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# RESEARCH AND TECHNOLOGY

## ANNUAL REPORT 1983

**Ames Research Center**  
Moffett Field, California



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LM101077E

Secondary Layer  
Aerodynamic Stall

Computation of Inviscid Compressible Flow

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# Introduction

This annual report illustrates some chosen achievements at the two sites of the Ames Research Center (Ames North and Ames Dryden) in the disciplines of Aeronautics, Life Science, and Space Science and Applications. The contents clearly demonstrate the diversity of the research activities at Ames, and provide an indication of the stimulating challenges that will be met in the future.

If you desire further information on any of the Ames research and technology programs, please contact the Research Assistant to the Center Director, Dr. David J. Peake, M.S. 200-10, NASA Ames Research Center, Moffett Field, California 94035.



C. A. Syvertson  
Director

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# Aeronautics

## Use of Concurrent Computer Architectures to Solve Computational Fluid Dynamics Problems

Concurrent computer architectures which are classified as multiple-instruction stream, multiple-data stream (MIMD) architectures, have been demonstrated to solve important computational fluid dynamics problems efficiently. The three codes used were based respectively on the full potential, Reynolds-averaged Navier-Stokes, and large eddy formulations of the Navier-Stokes equations, which describe fluid flow. The testbed used in this demonstration was a dual VAX 11/780 system sharing an MA780 Multi-Ported Memory. The speedup, the ratio of time required to solve the problem on a single processor to the time required on the multiprocessor system, are given in the table. It was also observed that simple extensions to FORTRAN could allow a typical programmer to achieve this level of efficiency. These extensions involve the concept of subprograms which can be executed concurrently and the concept of memory local to a concurrent subprogram and memory common to all concurrent subprograms. Additional development activities are under way to permit the use of these extensions on commercially available computers,

such as the CRAY X/MP, as well as supercomputers planned by Cray Research Inc. and ETA Systems Inc.

SPEEDUP ON A TWO PROCESSOR  
CONCURRENT PROCESSOR

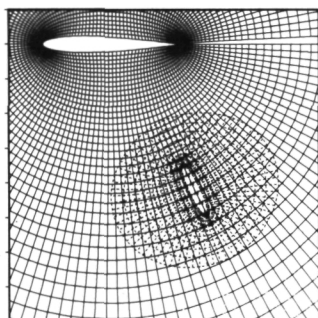
Program	Speedup*
Full Potential Code	1.55
Reynolds-Averaged Navier-Stokes	1.85
Large Eddy Simulation	1.98

$$*\text{Speedup} = \frac{2 \text{ processor CPU time}}{1 \text{ processor CPU time}}$$

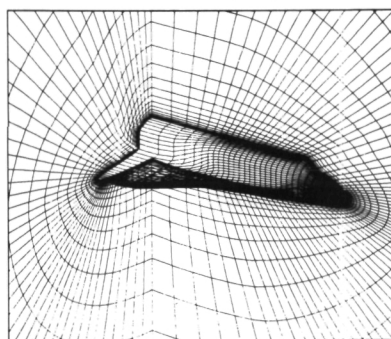
(K. Stevens, Jr., Ext. 5949)

## Grid Generation

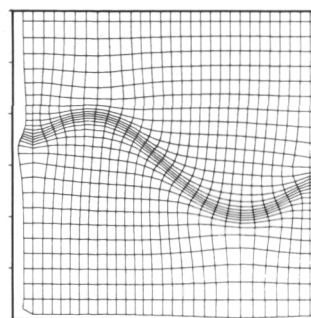
The discretization of the flow region surrounding geometrically complicated flight vehicles is one of the primary pacing items facing computational fluid dynamicists at this time. The grid influences the accuracy of the calculations as well as the efficiency with which they are performed. The discretization process involves two phases: (1) concept or topology definition, and (2) grid generation scheme selection. Various grid generation concepts are available including the component adaptive overlapping technology shown for an airfoil plus store. Differential grid generation schemes include elliptic, parabolic, and hyper-



GENERATION FOR AIRFOIL  
PLUS STORE



GENERATION ABOUT  
SHUTTLE ORBITER



GRID CLUSTERING ABOUT  
ARBITRARY SINE CURVE

*Grid generation*

bolic procedures. The discretized region about the Space Shuttle Orbiter obtained using a three-dimensional elliptic grid generation scheme is shown. A new elliptic grid generation scheme that is capable of generating orthogonal grids with a high degree of clustering control has been developed. A sample grid is shown in the accompanying figure where clustering has been implemented about an arbitrary sinusoidal curve.

(P. Kutler, Ext. 6032)

## Measurement and Calculation of Complex Turbulent Flows

An experimental study of the impingement of a plane oblique shock wave on a cylinder was undertaken in the Ames High Reynolds Number

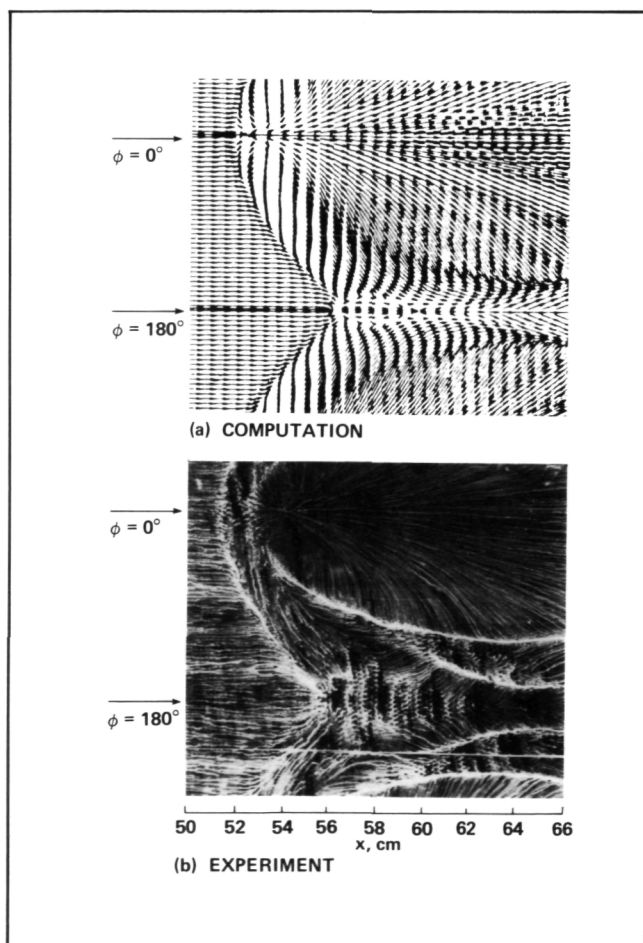
Facility. The goals of this study were to investigate the complex three-dimensional shock-wave boundary-layer interaction which occurs in many practical problems, such as the shock-wave impingement from the Shuttle nose on the external fuel tank, and to assess the ability to compute these complex flows. The experimental results revealed a highly complex flow field with two distinct adjacent separation zones, regions of high crossflow, and multiple reflected shocks and expansion fans. The numerical predictions, solving Reynolds-averaged Navier-Stokes equations with an algebraic turbulence model, agreed well with the measured results. A comparison of the measured and computed surface flow patterns is shown. However, some important measured flow details, such as the size and extent of the dual separation and the multiple reflected shock-expansion system, were not predicted, indicating the need for an improved turbulence model.

(J. Marvin, Ext. 5390)

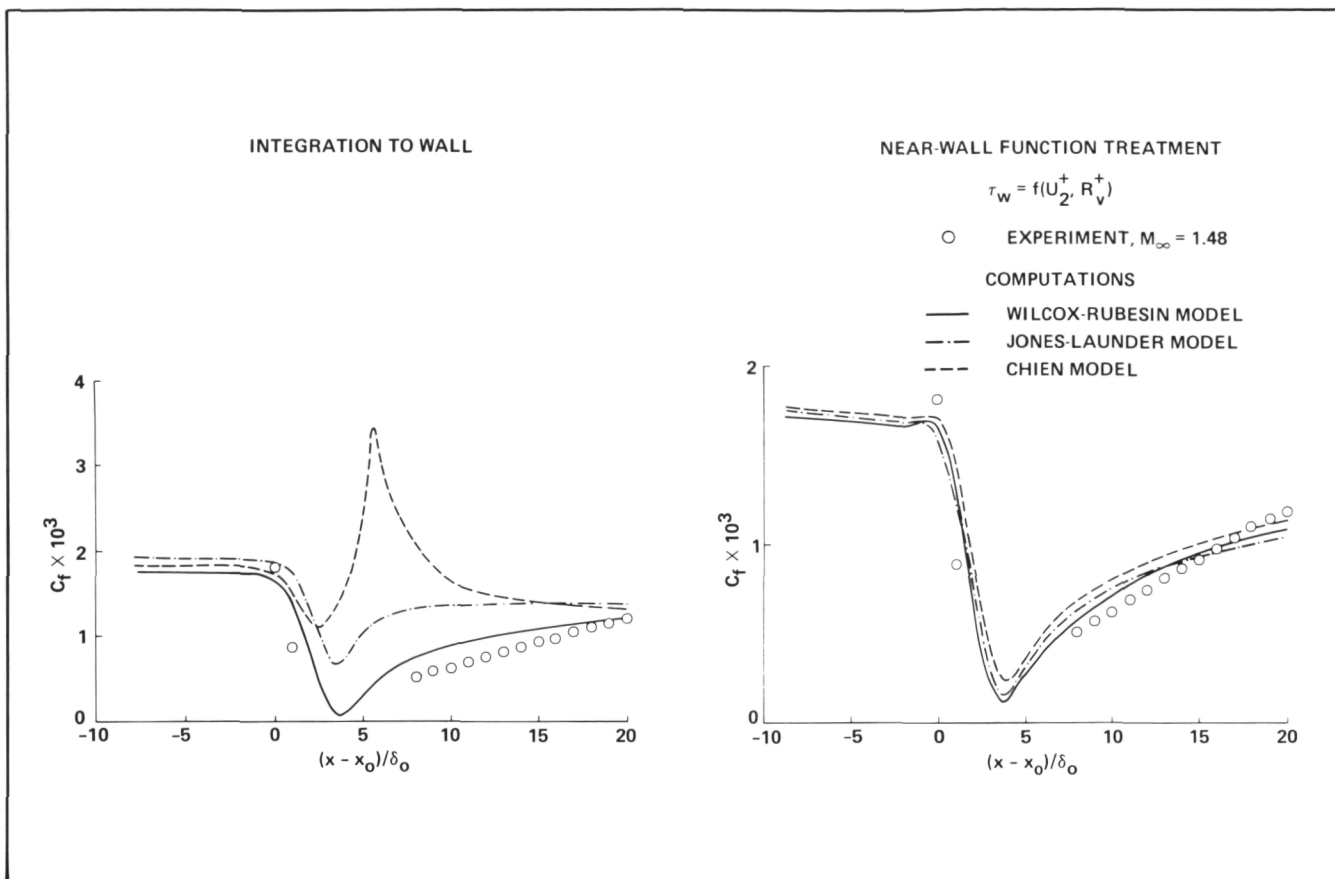
## Improvements in Turbulence Modeling

Wall-function boundary conditions have been developed for the two-equation turbulence models used in the solutions of the Navier-Stokes equations for complex compressible flows. With the use of wall functions the computer codes become more robust, achieve convergence in less CPU time (sometimes an order of magnitude faster), and the solutions are more accurate than results obtained using special low Reynolds number terms to account for the presence of a solid boundary. These new boundary conditions were tested for a variety of experimental results including two- and three-dimensional shock-wave boundary-layer interaction flows with and without separation. It was shown that the results using wall functions agree very well with the data for the complex compressible flows tested, provided criteria for the use of the wall functions are followed. Our present results compare solutions obtained when integrating to the wall and those using the new wall-functions, with experimental skin-friction data for a two-dimensional shock-wave boundary-layer interaction flow.

With the cost savings achieved, it is now possible to perform parametric studies of complex



*Computed and measured surface flow patterns*



*Recent improvements in applying various two-equation turbulence models*

three-dimensional flows using solutions of the Reynolds-averaged Navier-Stokes equations.

(J. Marvin, Ext. 5390)

## Computer Simulation of Afterbody Flow Fields

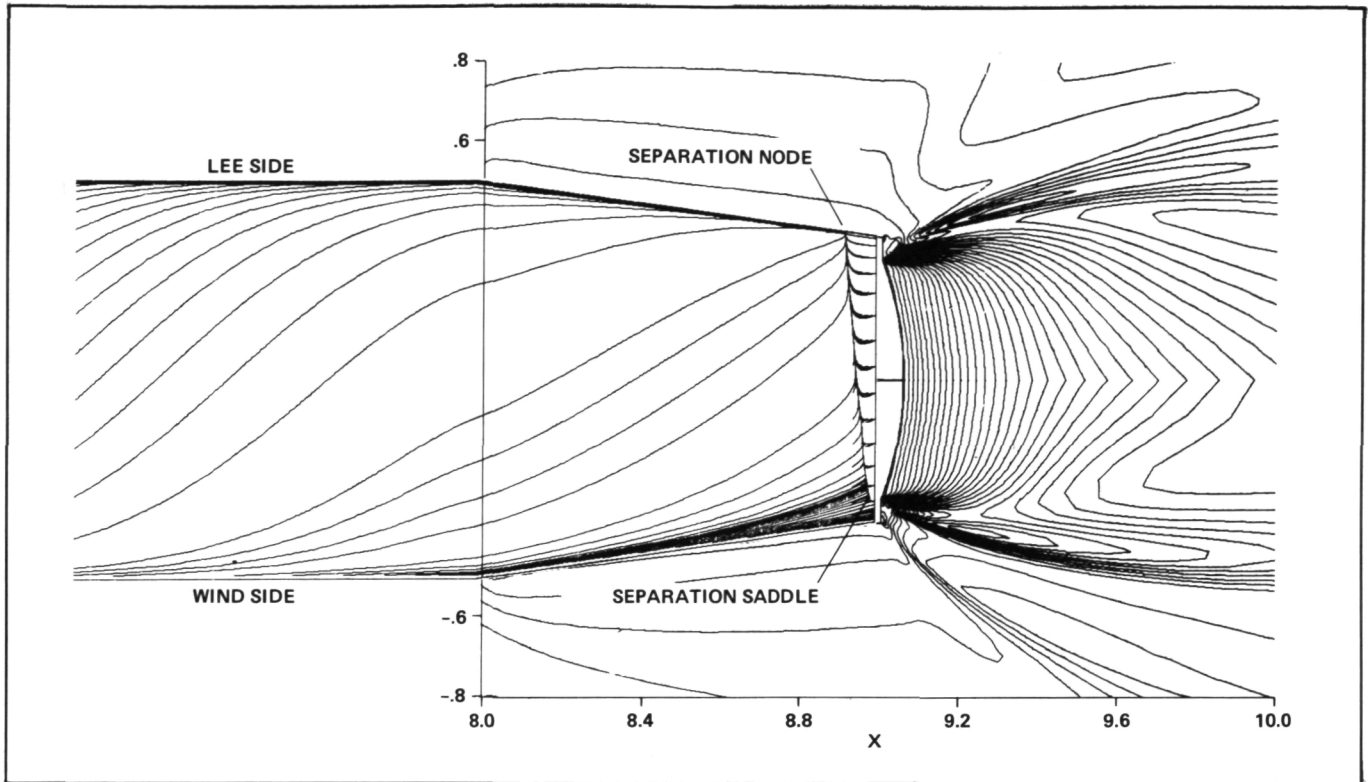
Predictive techniques for afterbody flow fields have been under development at Ames for several years in support of the Joint Army-Navy-NASA-Air Force (JANNAF) Interagency Propulsion Program. Solution of the three-dimensional, viscous, supersonic flow field over an afterbody at incidence with an exhaust plume requires the use of large databases and advanced computers. The ILLIAC IV and CRAY-1S computers have been used previously to obtain results at incidence with the exhaust plume represented by a solid body, and for zero incidence with a co-flowing jet.

The complete three-dimensional afterbody flow field with a co-flowing jet has now been

solved on a Control Data CYBER 205 supercomputer. The configuration was a cone-cylinder forebody followed by a conical afterbody with a centered, supersonic propulsive jet. Over 200,000 grid points were required to resolve the flow details near the surface and in the interaction region between the exhaust plume and the outer flow. The resultant database exceeded 5 million words. The thin-layer approximation to the time-dependent, compressible, Reynolds-averaged Navier-Stokes equations was invoked and the equations solved using the Beam-Warming implicit finite-difference algorithm.

The computed density contours in the plane of symmetry show the rapid expansion of the jet at the nozzle lip, which is followed by a strong recompression in the form of a barrel shock, and the slip surface between the exhaust plume and the outer flow. The expansion of the jet around the nozzle lip causes the flow to separate on the afterbody as shown by the surface streamlines. The afterbody drag is strongly influenced by this separated flow.

(G. Deiwert, Ext. 5894)



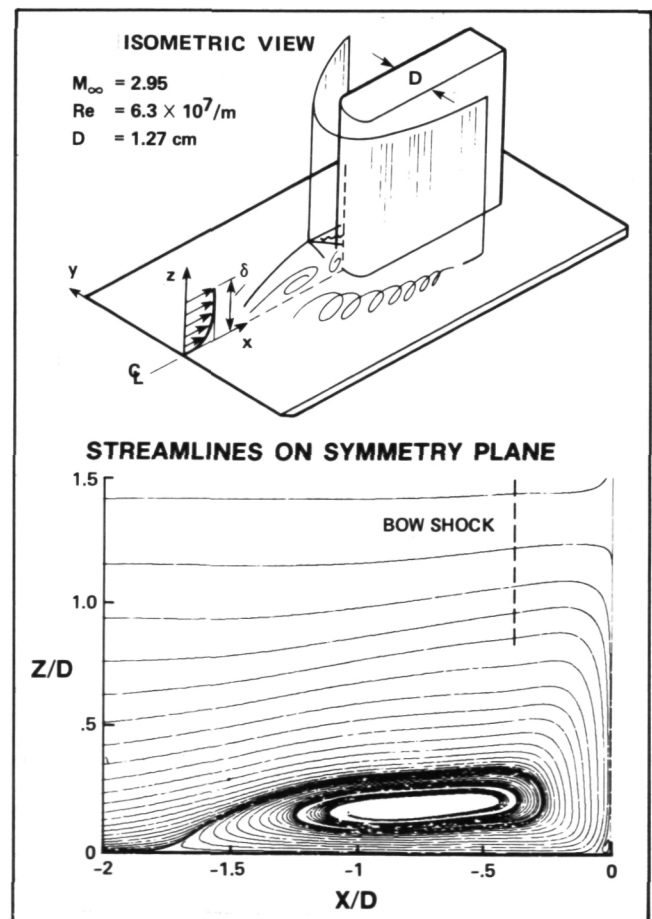
Computer simulation of afterbody flow field with co-flowing jet

## Computer Simulation of Flow Over Blunt Fin

The computer simulation of practical aerodynamic problems requires development of computer codes that faithfully reproduce the physical behavior of complex three-dimensional, viscous flow fields. A computer code has been developed to solve the thin-layer form of the three-dimensional, time-dependent, compressible, Navier-Stokes equations for high Reynolds number flows over an arbitrary geometry. MacCormack's new explicit-implicit finite-difference scheme is implemented in the code, which is written for the CRAY-1S computer.

The computer code has been applied for supersonic flow over a blunt fin mounted on a flat plate for a free-stream Mach number of 2.95 and for a free-stream Reynolds number of 800,000, based on the fin leading-edge diameter. The bow shock wave ahead of the blunt fin causes the boundary layer on the flat plate to separate near

*Three-dimensional separation around blunt fin in supersonic flow*



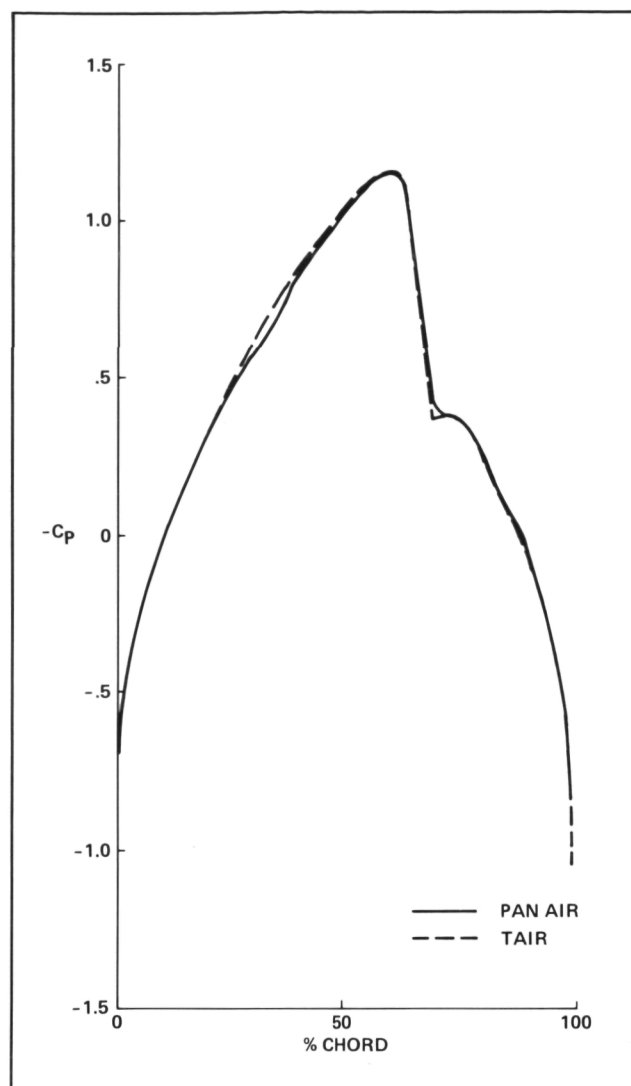
the base of the fin. The shock wave emanating from the separated flow region coupled with the bow shock wave, results in a lambda-type shock pattern. The three-dimensional separated flow region is characterized by a primary horseshoe vortex, which is shown by the traces of streamlines in the plane of symmetry ahead of the fin. A secondary separation exists at the base of the fin. Computed static pressures on the flat plate and fin leading edge show good agreement with measurements by Dolling and Bogdonoff of Princeton University. Observations of the existence of peak pressure, primary horseshoe and secondary vortices, and reversed supersonic zones, demonstrate that computations should complement and interact with wind-tunnel tests to comprehend complex fluid flow phenomena.

(C. Hung, Ext. 6420)

## Pan Air Development

PAN AIR is an advanced panel code being developed by Boeing Military Airplane Company (BMAC) under contract to Ames with cooperative participation from the Air Force, the Navy, and other NASA centers. The code predicts subsonic and supersonic flow about complete aircraft configurations and is being extended to predict transonic flow about these same configurations. During the past year, numerous applications of PAN AIR have been made for subsonic and supersonic cases. These include specific aircraft such as the F-16XL, the E7 STOVL fighter configuration, several advanced fighter configurations for AFWAL, and exploratory modeling studies including propeller slipstream interactions. At present, there are approximately 25 known organizations using PAN AIR.

Research during 1983 established that two-dimensional transonic flow problems with shock waves can be solved by combining PAN AIR panels with a rectangular set of grid points in physical space. Transonic flows about both blunt (NACA 0012) and sharp (circular-arc) leading-edge airfoils have been demonstrated. Chordwise pressures for supercritical flow about an 18% circular-arc airfoil show excellent agreement with the results obtained from TAIR, a finite-difference two-dimensional transonic code. Since surface-conforming grids are not used, the extension of this method to transonic flow about complete aircraft appears to be practical. This exten-



*Computed pressure distributions on 18% thick circular-arc airfoil;  $M_\infty = 0.73$ ,  $\alpha = 0^\circ$*

sion is being pursued under a transonic PAN AIR contract with the Boeing Company.

(L. Erickson, Ext. 6216)

## Transonic Aeroelastic Analysis

The study of transonic aeroelastic characteristics of wings is important, especially for the design of modern fighter aircraft. The transonic regime, which is optimum for cruise, may be critical from an aeroelastic point of view. For example, flight tests have indicated that the B1-wing has aeroelastic instability points at

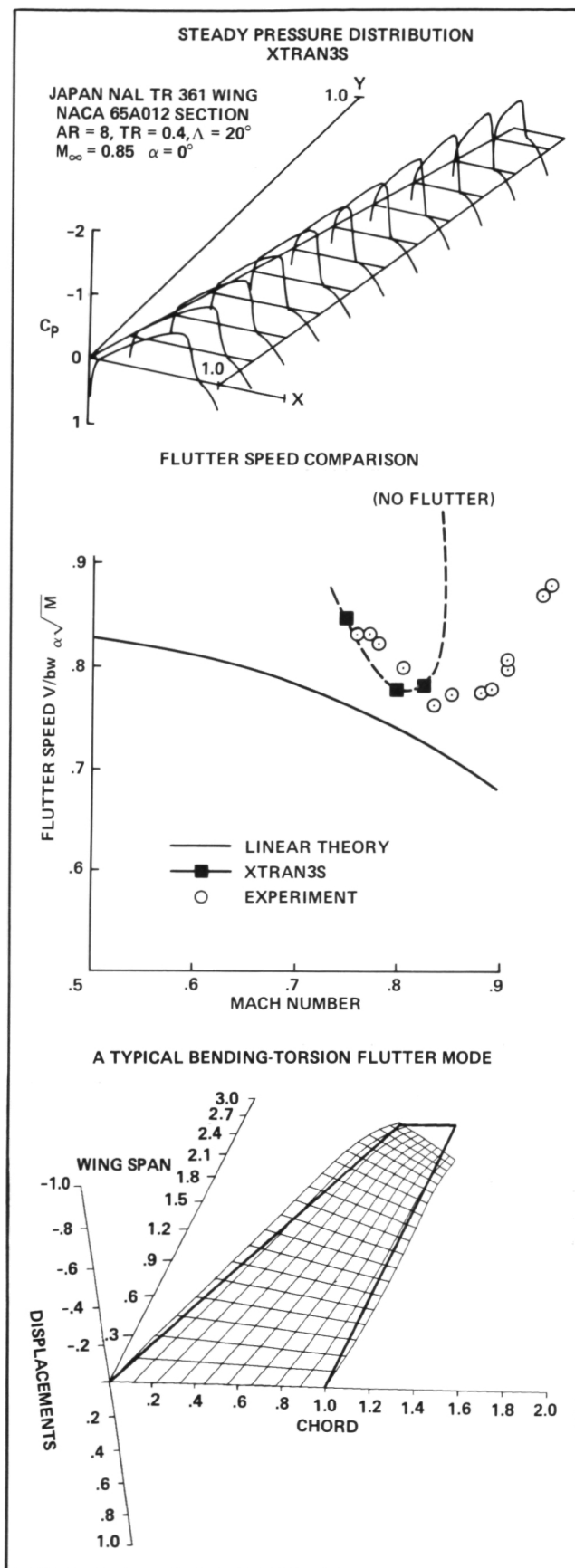
$M = 0.72$  and at  $M = 0.90$ . To study accurately the transonic aeroelastic characteristics of wings, a computer code, XTRAN3S-Ames, has been developed. This code solves the small-disturbance, unsteady transonic, aerodynamic equations of motion simultaneously with the structural modal equations of motion. Time-accurate, finite-difference schemes are used for solving both the aerodynamic and aeroelastic equations of motion. The code can be used for both coupled and uncoupled aeroelastic analyses. In addition, this code can account for viscous effects. The code has been successfully applied to typical transport as well as to fighter wings.

(P. Kutler, Ext. 6032)

## Unsteady Transonic Rotor Aerodynamics by a Finite-Difference Method

A computer code was developed to calculate the three-dimensional unsteady transonic flow past a nonlifting helicopter rotor blade. The code solves the transonic full-potential equations in a blade-attached moving frame of reference by a time-marching implicit scheme. At the far field, a set of first-order radiation boundary conditions is imposed so that the reflection from outgoing wavelets at the computational boundaries is minimized. Computed results show good agreement with available test data for both straight- and swept-tip blade geometries. A comparison among unsteady and quasi-steady calculated results, and ONERA experimental data for a straight-tip blade has been made. A time-retardation of the shocks due to unsteadiness can be seen in this comparison as follows: (1) the shock at  $120^\circ$  azimuth is stronger than that at  $90^\circ$  azimuth, (2) the quasi-steady calculation predicts no shock at  $150^\circ$  azimuth, whereas the unsteady calculation catches the shock measured in the experiment, and (3) the quasi-steady calculations predict stronger shock waves in the first quadrant and weaker shock waves in the second quadrant. This comparison shows that the quasi-steady theory does not adequately predict the strong shock waves that persist over a range of azimuthal angles at extremely high advance ratios.

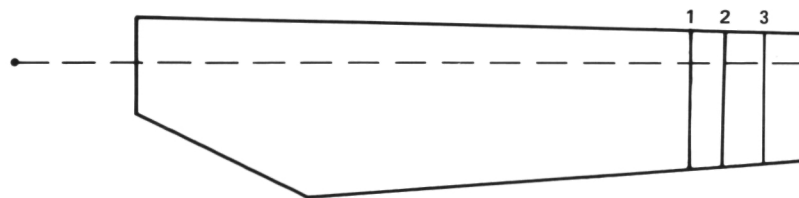
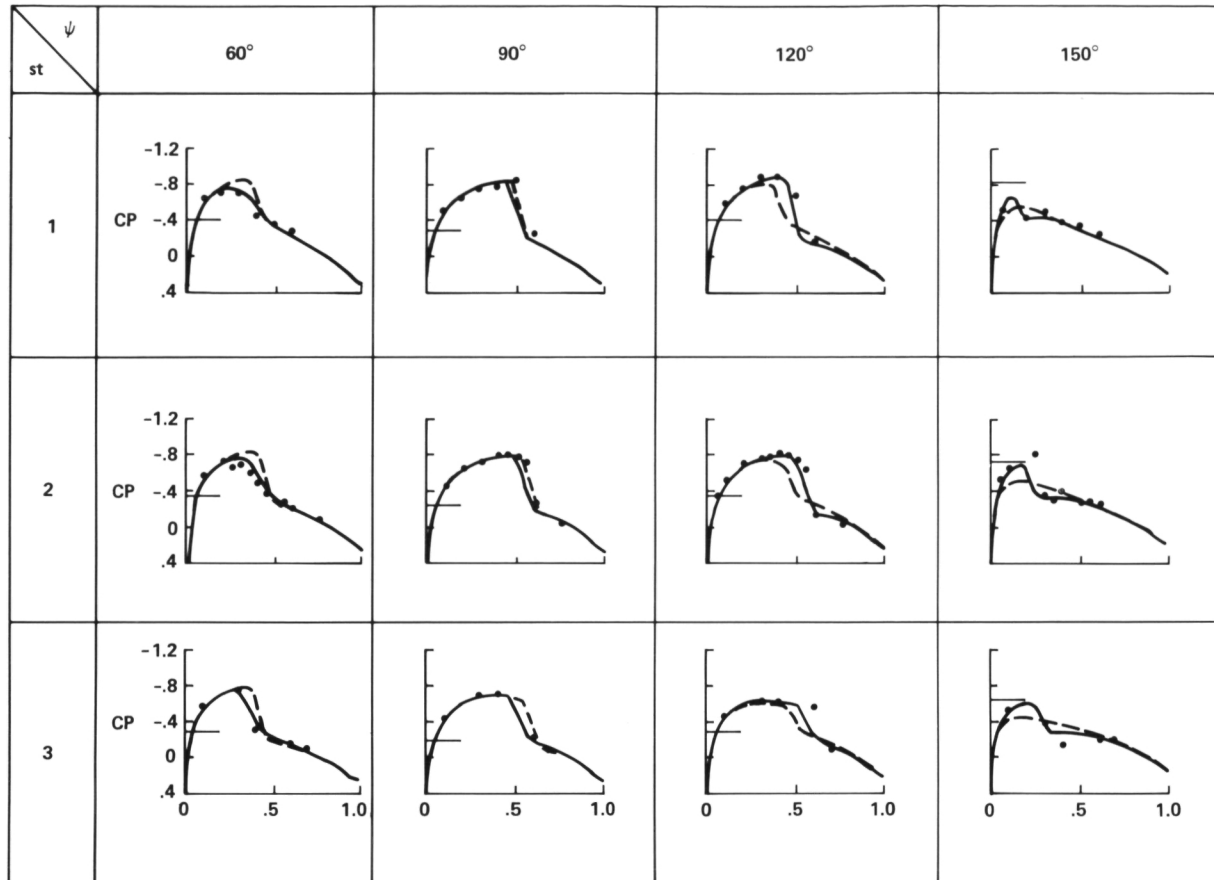
(I-C. Chang, Ext. 6396)



*Aeroelastic analysis of a transport wing*

$$\mu = 0.55, V_{\infty} = 110 \text{ m/sec}, \omega R = 200 \text{ m/sec}$$

— UNSTEADY  
 --- QUASI-STEADY  
 • ONERA DATA



Comparison between unsteady and quasi-steady calculated results, and ONERA test data, on a two-blade rotor

## Turbulence Measurements in Supersonic Flows

A study to compare the Reynolds normal and shear-stress profiles obtained with dual-beam laser Doppler and hot wire anemometry was done in a turbulent shear layer at a free-stream Mach number of 2.9. The results show that both techniques

are able to provide accurate measurements of streamwise velocity fluctuations. The laser Doppler velocimeter was more successful than the dual-sensor hot-wire probes in determining the vertical velocity fluctuations and the turbulent shear stresses because of intrusion problems caused by the hot wires.

(J. Marvin, Ext. 5390)

## Laser Velocimetry for Low-Speed Aerodynamics Research

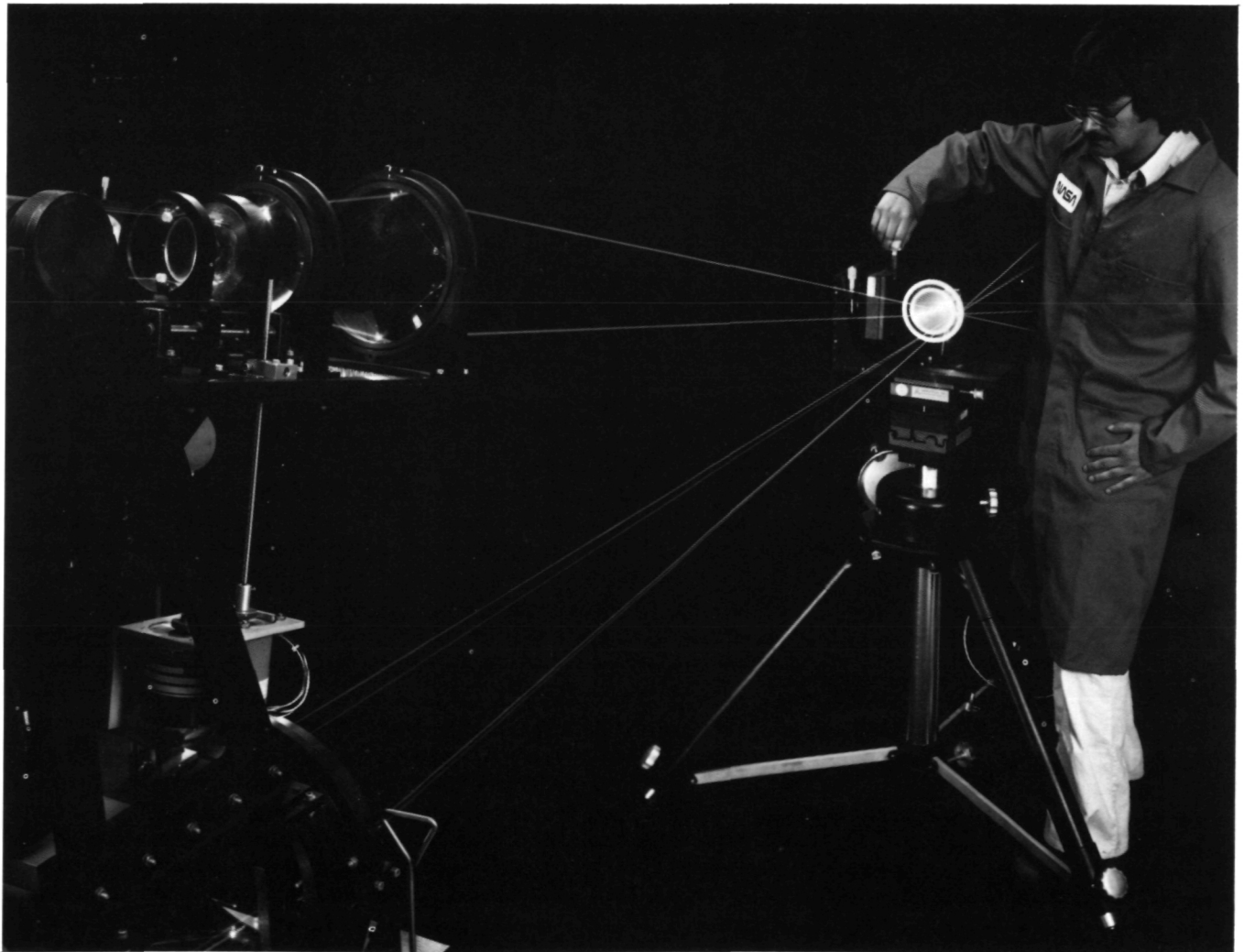
A long-range laser velocimeter for use within the test section of the Ames 40- by 80-Foot Wind Tunnel has recently been completed. With minor changes, the optical range of the instrument can be extended for use in the Ames 80- by 120-Foot Wind Tunnel as well as in the Ames Outdoor Aerodynamic Research Facility.

The long-range velocimeter is a single-color, dual-beam backscatter system that is capable of sensing two orthogonal components of velocity. Under development is a dedicated stand-alone microprocessor-based controller/interface unit that will be used (with or without a computer) for test point position control, data acquisition,

and front-panel display of position and measured velocity. The controller is user-oriented and will greatly simplify implementation of the velocimeter for routine wind-tunnel testing.

The recently developed laser velocimeter optical system has been optimized for applications in the Ames 7- by 10-Foot Wind Tunnel. The instrument is a three-color, dual-beam backscatter velocimeter that simultaneously measures all three mean velocity components. The three-dimensional laser velocimeter is calibrated by means of a newly developed velocity reference source that is accurate to 0.1%. Use of this device allows the entire velocimeter system (optics and signal processing electronics) to be calibrated (using a special matrix algebra technique) to better than 1%.

Because the three-dimensional velocimeter involves nonlinear positioning of five stepper motors, data transfer from three signal processors,



*Optical system of long-range laser velocimeter*

and communication with three frequency synthesizers, the velocimeter has been interfaced to a dedicated high-speed minicomputer with extensive peripheral and input/output capability. The computer automatically performs test point path control as well as implements special data acquisition, reduction, and display methods; also, the software has been designed to be highly interactive so that the scientist can most effectively use the velocimeter for aerodynamics research.

Using the three-dimensional velocimeter, we have developed a new technique wherein the test point is moved in such a fashion that it follows along a mean streamline, and the resulting streamline is displayed on the computer graphics as the motion takes place; using this technique, it is possible to gain additional insight into the fluid mechanics of complex flows.

(K. Orloff, Ext. 5033)

## Computer Control of Wind-Tunnel Laser Velocimeter System

In the High Reynolds Number Channel, a five-fold increase in the data rate obtainable was accomplished by interfacing a laser-Doppler velocimeter position controller with a PDP11/34 computer. Previously, a tunnel test had to be stopped to allow for a manual repositioning of the laser velocimeter system, which thereby reduced the amount of data that could be recorded in a given run.

Eighty inches of motion are currently available with a resolution accuracy of 0.001 inch.

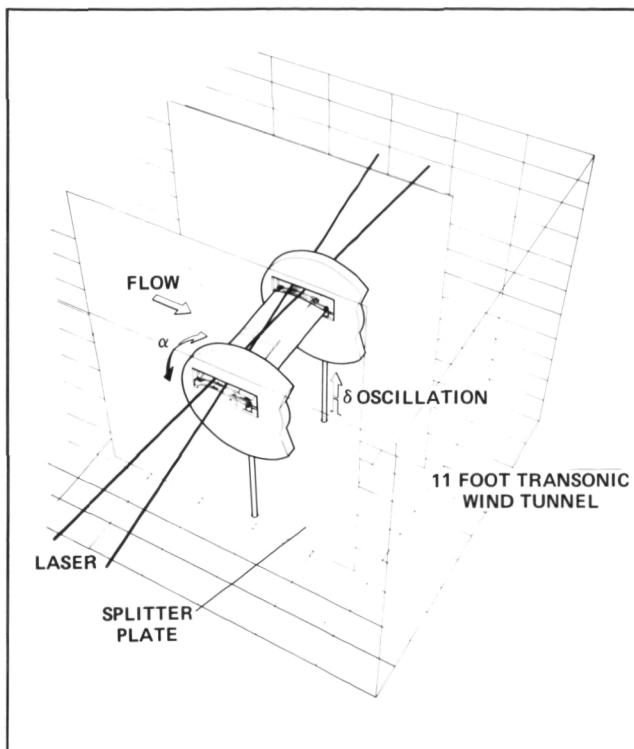
(R. Donaldson and D. Harrison, Ext. 6502/6496)

## Oscillating-Flap Tests

Tests were conducted to determine the characteristics of an oscillating flap on a model of the NACA 64A010 airfoil. The purpose of the investigation was to obtain data for comparison with computations and to add to the database for designing control-configured vehicles.

The airfoil was mounted between splitter plates in the Ames 11-Foot Transonic Wind Tunnel.

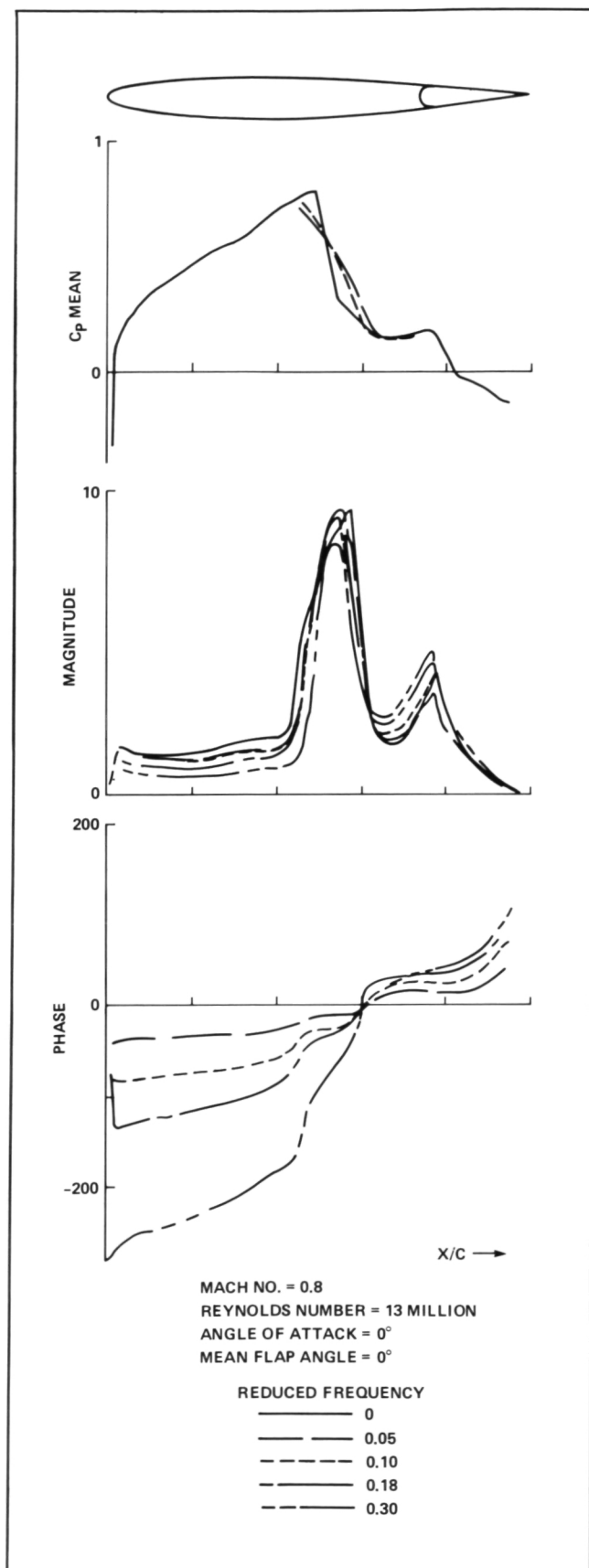
Test Mach numbers ranged from 0.5 to 0.85 with chord Reynolds numbers up to 13 million. Angles of attack were  $0^\circ$  to  $8^\circ$ . Mean deflections of the 25% chord flap were as high as  $12^\circ$ . The flap was oscillated at amplitudes from  $1^\circ$  to  $6^\circ$  and frequencies up to 50 Hz.



*NACA 64A010 airfoil with oscillating flap*

Steady-state and dynamic pressure measurements were made on the airfoil and tunnel walls. Each of the dynamic signals together with flap position, strain, and acceleration, were conditionally sampled 40 times per cycle and fed into a minicomputer. The measurements at each phase of the cycle were then averaged over 100 cycles and stored, yielding approximately 25,000 data recordings for each of the more than 80 pressure transducers. On-line integration, plotting, and printing were available on demand. The dynamic-pressure magnitude (first harmonic of the Fourier series) has maxima at the shock wave and at the flap leading edge. At these test conditions, where there is no flow separation, the frequency has little effect on magnitude but a large effect on phase.

Flow-field characteristics were quantified by passing laser beams through windows in the wind-tunnel walls and splitter plates. Using pulses triggered by the flap oscillation, holographic interferograms and shadowgraphs of the flow



Upper surface pressures on NACA 64A010 airfoil

field were recorded for later data reduction. In the wake, measurements were made with a two-color laser velocimeter and with a probe containing hot films and pressure transducers.

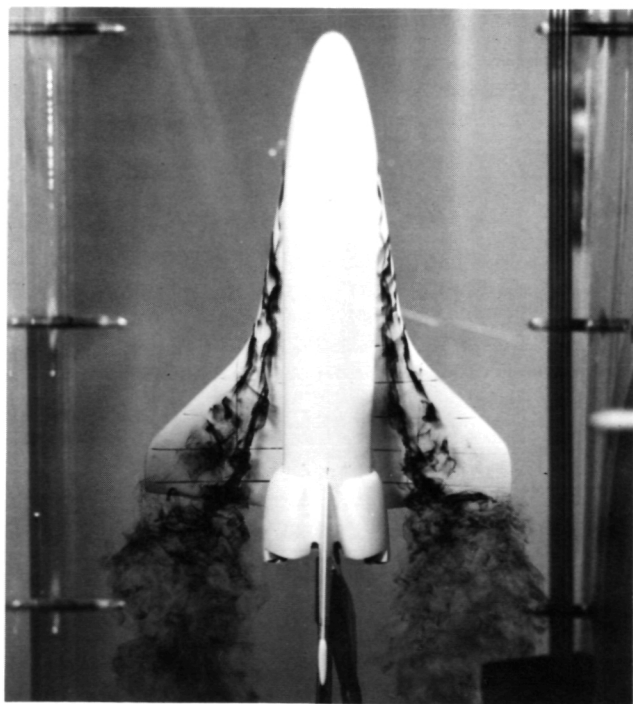
(D. Buell, Ext. 6116)

## Flow Visualization Water Tunnel

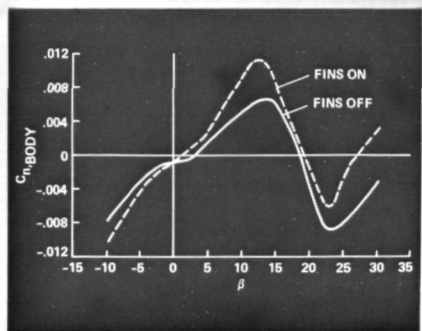
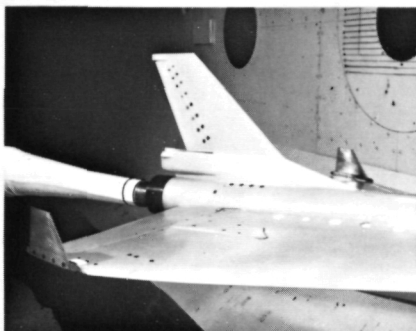
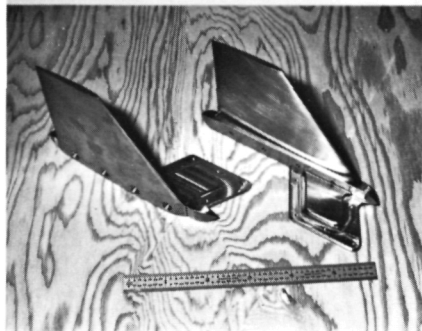
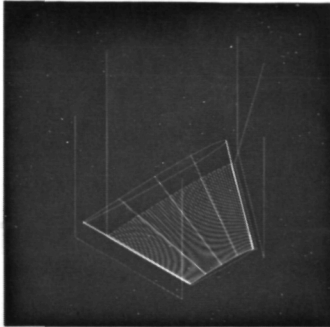
Ames-Dryden has constructed a water-tunnel similar in design to the one at Northrop (Hawthorne, California). The water tunnel has a 40.6- by 60.9-cm (16- by 24-in.) test section and all tests are conducted at a Reynolds number of approximately  $1.3 \times 10^5$ /m (40,000/ft). Visualization of the flow field is provided by dye injected through tubing within the forebody and wing of the test models. Color photographs and videotapes of the vortex patterns are obtained throughout a range of angles of attack.

Typical vortex formations about a model of the Shuttle Orbiter have been demonstrated. Shown is a tight, well-defined vortex formed from the wing leading-edge extension.

(J. DeFrate, Dryden Ext. 3704)



Vortical flow about model of Shuttle Orbiter at angle of attack



*Use of a CAD/CAM system in research at Ames*

## Computer-Aided Design and Manufacturing

A computer-aided design and manufacturing (CAD/CAM) system is being used at Ames to generate aircraft geometry for aerodynamic analysis and to fabricate wind-tunnel model parts. An interactive program was developed for the CAD system to automate the modeling of aircraft configurations. The user is able to construct wings, tails, fuselages, and nacelles by specifying aircraft geometry parameters. The program interprets these parameters to generate the curves and surfaces that define the aircraft components in the geometry database. The program gives the researcher a method for visualizing an aircraft configuration and then quickly changing parameters to modify the design. The geometry database is then used for defining analysis input and for wind-tunnel model fabrication.

The usefulness of the CAD/CAM system to aid in aerodynamic research was proven during a recent wind-tunnel test of a V/STOL fighter model. Researchers decided during the ongoing wind-tunnel test that the lateral/directional stability of the model should be investigated further after reviewing the data taken. The effects of additional vertical surface area on the model, such as winglets, would be a useful addition to the test.

The aircraft modeling program of the CAD/CAM system was used to define quickly appropriate winglet parts. Numerical control tool paths were generated by the CAD/CAM system to machine a pair of winglets. The total process of design, analysis, fabrication, and installation of the parts on the wind-tunnel model took less than 1 wk. The additional vertical fins improved the directional characteristics of the model and thus provided the aircraft designer with parametric information to improve further the configuration design.

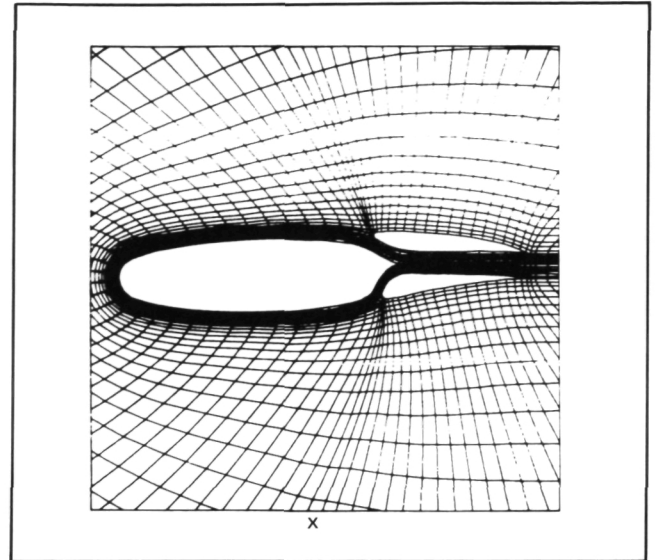
(F. Enomoto, Ext. 6133)

## Computational Aerodynamics of Augmentor-Wing Section

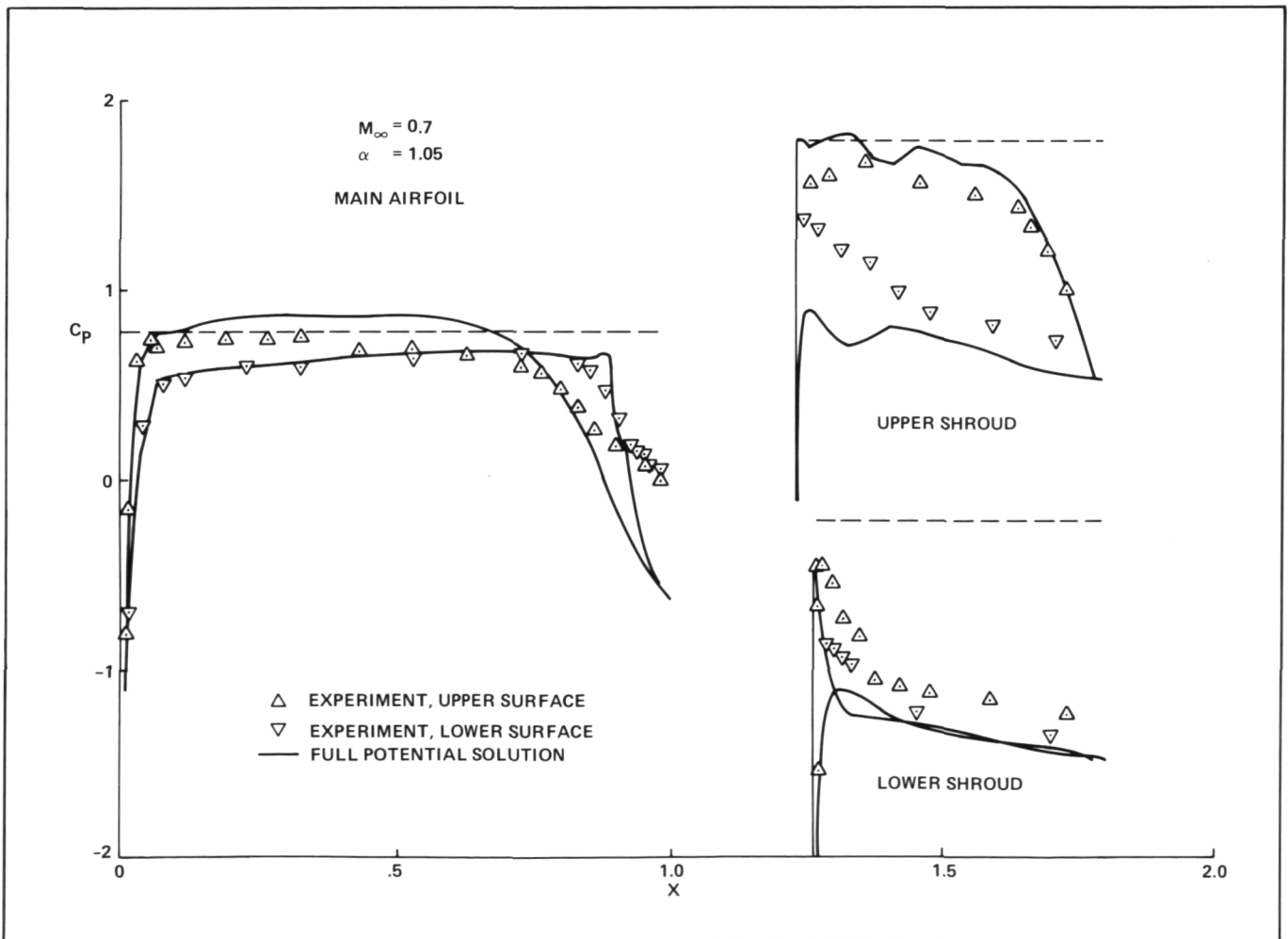
The Augmentor-Wing has been described as having several aerodynamic advantages over a more conventional single-foil supercritical section of the same overall thickness-chord ratio. The TAIR (Transonic AIRfoil analysis) full-potential code was modified to solve the multi-element airfoil configurations of the augmentor-wing type. This code uses a fully implicit approximate factorization scheme (AF2) to solve the transformed

full-potential equation in a general, nonorthogonal, body-conforming coordinate system. Computational results are compared with experiment for a flow with a free-stream Mach number of 0.7 and an angle of attack of  $1.05^\circ$ . Typical results obtained from the augmentor-wing full-potential code on a CRAY-1S computer required about 10 sec of CPU time for a three order-of-magnitude drop in the maximum initial residual. The low cost of running the code makes it very attractive for numerical optimization studies designed to obtain ideal aerodynamic surface shapes.

(P. Kutler, Ext. 6032)



*Numerically generated grid about augmentor-wing section*



*Pressure coefficient distribution for the main air-foil, upper, and lower shrouds. Note:  $C_p$  is increased (decreased) by one for the upper (lower) shroud*

# V/STOL Fighter Configuration Aerodynamics

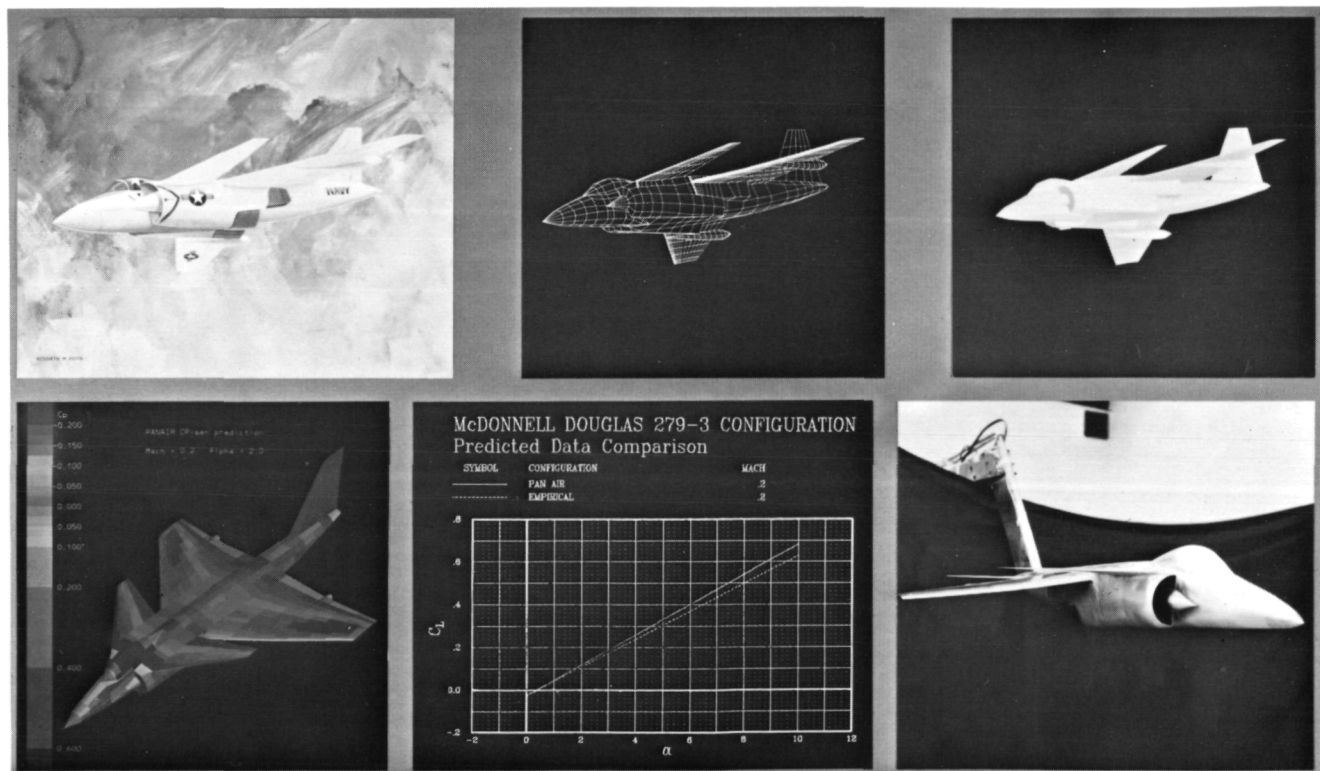
Aerodynamic technology is being developed for twin- and single-engine V/STOL fighter aircraft in two joint NASA, Navy, and industry programs. Contractors have defined promising V/STOL and STOVL concepts, conducted preliminary aerodynamic analyses, and identified configuration-dependent aerodynamic uncertainties. Wind-tunnel tests are being conducted in NASA Ames facilities to resolve the uncertainties. Data are being analyzed by NASA and by the contractors.

Reports of the twin-engine-model test data were published this year in the form of NASA contractor reports and technical papers. Fabrication of single-engine V/STOL models by General Dynamics (G/D) and McDonnell-Douglas (MCAIR) has been completed. The G/D design (E7) features a combination of thrust-augmenting ejectors and a deflecting nozzle for propulsive lift, whereas the MCAIR design (279) uses deflected thrust in a four-poster configuration. The first

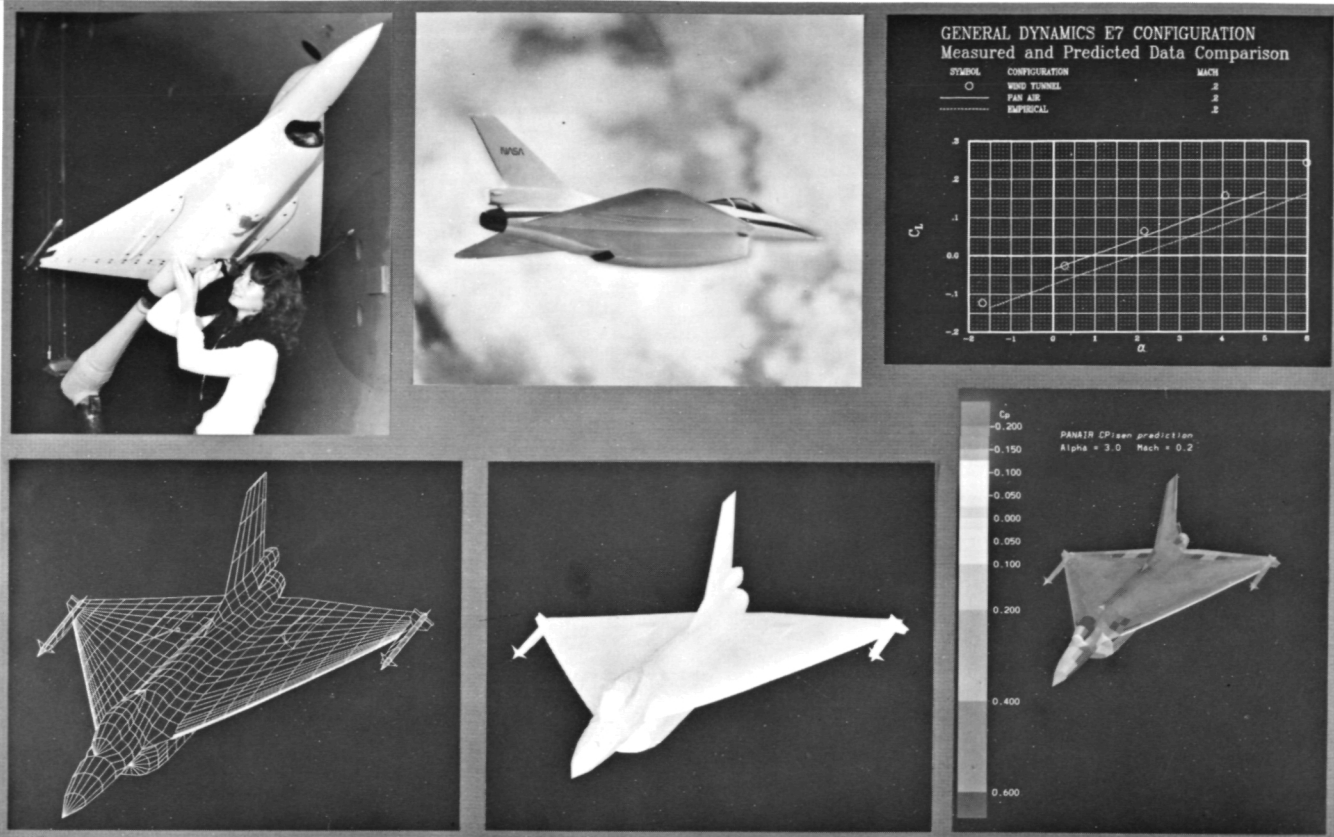
test of the G/D configuration was conducted in the Ames 12-Foot Pressure Wind Tunnel during Jan. 1983. This flow-through model was tested at a Mach number of 0.2 with angles of attack ranging from  $0^\circ$  to  $90^\circ$  and angles of sideslip from  $-10^\circ$  to  $30^\circ$ . The test emphasized trimmed aerodynamic characteristics, component build-up effects, and high-altitude, longitudinal and lateral/directional stability and control. Extensive testing of both models is planned for 1984 in the Unitary and 12-Foot wind tunnels.

In addition to the model construction and test activity, computer-generated geometries have been developed for both single-engine designs using the CAD/CAM system in the Aircraft Aerodynamics Branch. Aerodynamic predictions are being made on these geometries prior to the wind-tunnel tests using PAN AIR and other prediction methods. In addition, stream angularity uncertainties from the aforementioned E7 test are being investigated using PAN AIR. The aircraft geometry has been modeled in simulated free-stream flow and in a simulated wind-tunnel environment with the floor-mounted support system.

(D. Durston and M. Madson, Ext. 5855/6134)



McDonnell-Douglas 279 single-engine V/STOL configuration



General Dynamics E7 single-engine STOVL configuration

## Propulsion Simulation

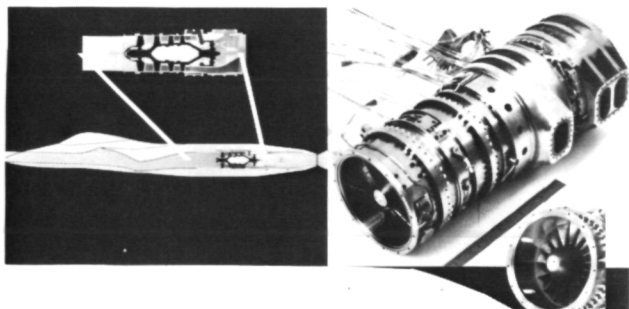
A promising wind-tunnel test technique for simulating complete propulsion-system-induced effects on highly integrated aircraft configurations is being developed at Ames in cooperation with the Air Force Flight Dynamics Laboratory. This technique involves the use of miniature, high-pressure, turbine-powered jet engine simulators to produce scaled-inlet and exhaust-nozzle flows simultaneously. These 3-in.-diam mini-engines can simulate inlet and nozzle flows for engine pressure ratios in excess of 3.6:1 and are known as Compact Multimission Aircraft Propulsion Simulators (CMAPS). A wind-tunnel test using two of these miniature engines to simulate complete propulsion effects was conducted in the 11-Foot Transonic Wind Tunnel in May 1983. The model was a STOL fighter configuration with two-dimensional deflecting nozzles. The objective of this test was to measure the differences in airframe/propulsion system interactions measured using the CMAPS and those measured using the conventional technique (flow-through and jet-effects from a previous test). During the present

test, inlet mass flow ratio and nozzle pressure ratio were investigated over a Mach number range of 0.4 to 1.4 for angles of attack of  $-2^\circ$  to  $15^\circ$ . The two simulators performed well throughout the test, logging about 140 hr.

(R. Bailey, Ext. 5990)



Twin-engine CMAPS model in Ames 11-Foot Transonic Wind Tunnel



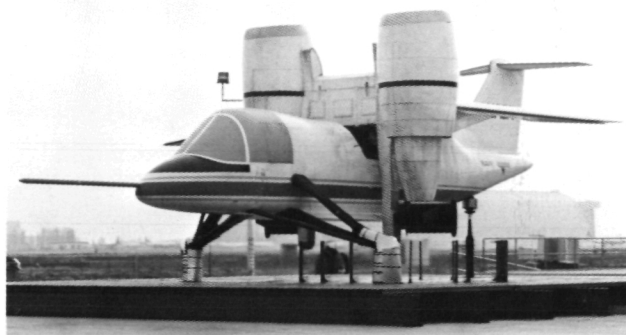
*Wind-tunnel model propulsion simulator*

## Tilt-Nacelle Ground-Effect Investigation

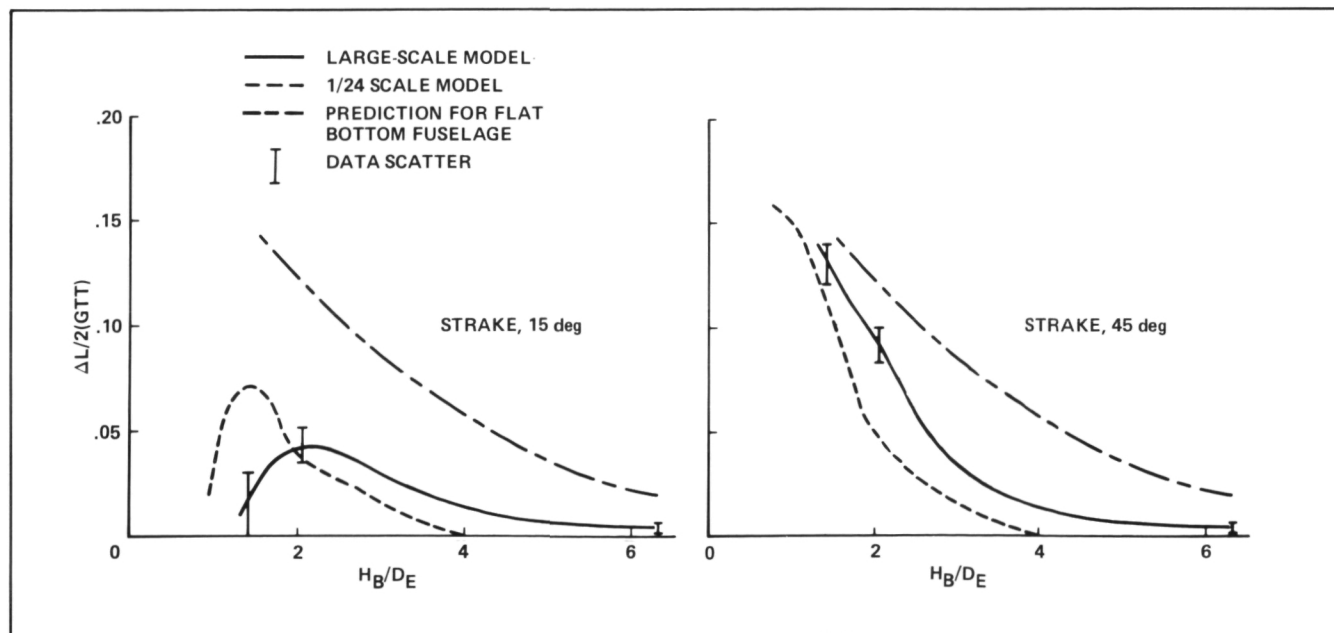
The study of the tilt-nacelle subsonic V/STOL concept has included an extensive and basic evaluation of hover characteristics in and out of ground effect. As is the case for the overall tilt-nacelle program, the ground-effect effort has been supported jointly by NASA, the U.S. Navy, and Grumman Aerospace Corp. Initial work was done on a generic test installation and a 1/24th-scale model. Preliminary measurements using the full-scale TF 34 powered model were obtained in 1980 and reported subsequently. The objective of the ground-effect investigation has continued to include effects on aircraft forces and moments, control about all axes, inlet re-ingestion, and component loads. In all experiments, attempts have

been made to plan external, onboard instrumentation to supply the foregoing information as well as sufficient measurements on the flow patterns surrounding the aircraft.

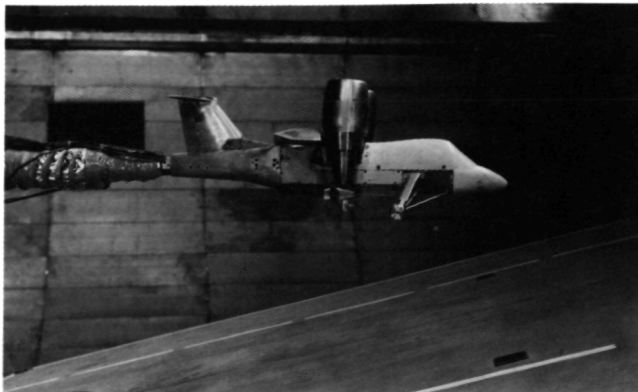
The most recent tests have included more hover testing of the full-scale model described above and hover tests of an 11%-scale model shown installed in the Ames 40- by 80-foot test section. This model was powered by air-driven TF 34 simulators and the ground board orientation with respect to the model was changed to simulate aircraft pitch and roll as well as changing ground height. Both models have extensive onboard instrumentation. As well as surface pressure measurements, internal balances were used such that, in the case of the large model, the forces on the nacelle assembly and control vanes



*Large-scale tilt nacelle model installed at the Ames Outside Aeronautical Research Facility (OARF)*



*Powered lift increment in ground effect*



11% scale tilt nacelle model installed in the Ames 40- by 80-Foot Wind Tunnel for hover tests

could be isolated. In the case of the 11% scale model, forces on the nacelles and on the wing and fuselage assembly, can be measured for evaluation of component interference effects.

Typical results of the investigation show that the ratio of the lift increment to the total engine gross thrust is a function of ground height. The strakes located under the fuselage enhance lift by trapping the fountain caused by the merging of the two propulsive jets. The recent large-scale tests have also established that there is no re-ingestion problem, even in a 15 to 20 knot wind, and that the control vanes combined with ground effect do not back-pressure the engine core at the maximum control deflections.

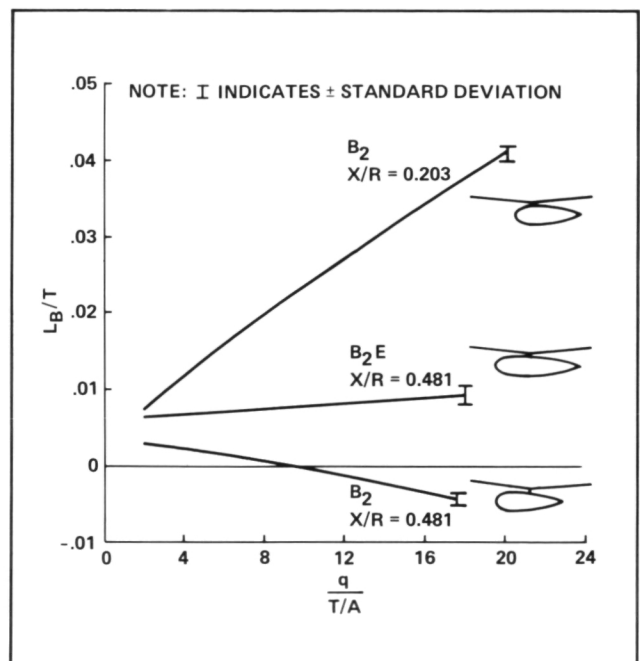
(D. Koenig, Ext. 5047)

## Small-Scale Rotor/Fuselage Interaction Tests

An experimental investigation was conducted in the Ames 7- by 10-Foot Wind Tunnel to obtain quantitative measurements of the steady-state aerodynamic interactions occurring in a simplified helicopter system consisting of a rotor and a body of revolution. The test was similar to that conducted in FY 82, which used a 1/6-scale model of the Rotor Test Apparatus (RTA). The most recent test used a 1/6-scale model of the body to be used for full-scale aerodynamic testing in the Ames 40- by 80-Foot Wind Tunnel.

Results showed that the body longitudinal aerodynamic characteristics were significantly affected by the presence of a rotor and hub, particularly with respect to the effect of the body

longitudinal position on the body lift ( $L_B$ ) to rotor-thrust ( $T$ ) ratio. The body was completely isolated from the rotor system such that the body loads did not include any of the rotor loads but did include the interaction effects due to the presence of the rotor system. The body lift was substantially reduced when the body was moved forward relative to the rotor. By comparing with an extended body that has the same nose and tail shape, the relative contributions of the nose and tail positions can be observed. It was concluded that a major part of this trend is due to the hub and that the hub interference should be included in analyses to predict rotor/body interactions. The effects of vertical separation of the rotor and body, body angle of attack ( $\alpha_B$ ), and rotor tip-path-plane angle ( $\alpha_{TPP}$ ) were also obtained.



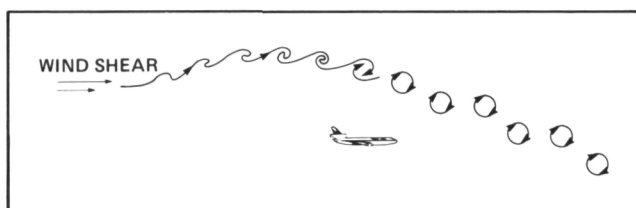
Effect of body longitudinal position on body lift;  $\alpha_B = 0^\circ$ ;  $\alpha_{TPP} = 0^\circ$

Since the hub loads cannot be separated from the rotor loads, it is not possible to determine which component is responsible for changes in rotor performance. The data indicating the effect of the body on the rotor performance were inconclusive, because the hub was not representative of a scaled configuration. Accurate scaling of the hub and control system are necessary so that full-scale testing may be the best approach to obtain these data.

(M. Betzina, Ext. 6679)

## Clear-Air-Turbulence Vortices

The nature and cause of clear air turbulence is being investigated in cooperation with the National Transportation Safety Board, using the flight records available from airline encounters with severe turbulence. These severe encounters are usually at altitudes from 34,000 to 40,000 ft and are associated with strong wind shears in the jet stream or with standing waves in the lee of a mountain barrier. The investigation indicates that the severe encounters result from a breakdown of wind shear layers into (Kelvin-Helmholtz) vortex arrays.



*Reconstruction of vortex patterns in mountain waves using airline flight records*

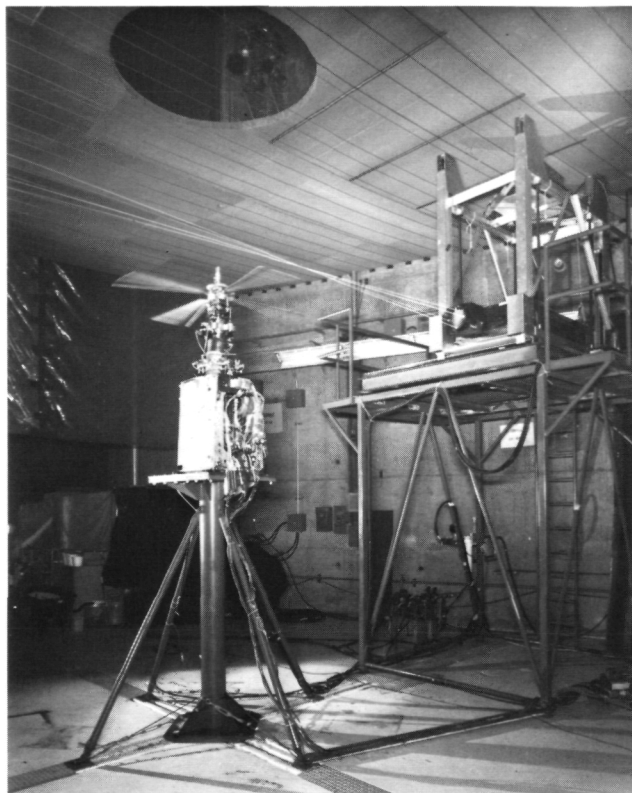
To identify and analyze vortex patterns (i.e., vortex strength, size, and spacings) new analysis methods have been developed that use aerodynamic potential theory to mathematically describe vortex flow and associated wind patterns. The vortex pattern is determined through a fit to the time history of the winds experienced in severe turbulence encounters. The results of this analysis indicate that the vortices can be up to 1,000 ft in diameter, at spacings of about 3,000 ft, with whorls of wind above 60 fps. This study presents the first identification and analysis of vortex arrays from actual flight data and provides a better understanding of this continuing problem in airline operations.

(R. Wingrove, Ext. 5429)

## Hover Test Chamber for Helicopter Rotors

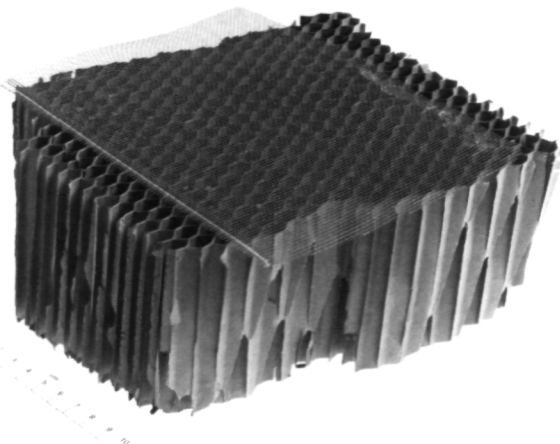
A hover test chamber has been developed for performing small-scale rotor experiments. The test chamber will be used for investigating hover performance, rotor airloads, and details of the

rotor wake. The chamber is 36 ft in diameter and 90 ft high. A 6-ft-diam rotor has been installed and testing has been initiated. The rotor is located 12 ft above the floor and operated with the thrust directed downward and the wake directed upward.



*Experimental set-up in the hover test chamber*

Due to the height-to-width ratio of the test chamber, the upwardly expanding rotor wake can interfere with the general recirculation pattern. Testing indicated that the recirculation was unsteady to the extent that the rotor thrust and torque varied randomly  $\pm 6\%$ . The test chamber was then modified by installing a wall-to-wall flow straightener located 1.1 rotor diameters above the rotor with a circular cut-out for the wake which had a diameter that was 97% of the rotor diameter. This flow straightener has a nominal hole depth-to-diameter ratio of 10 and is composed of 3.5-in.-thick paper honeycomb with a layer of 16X18 mesh plastic screen bonded on top. This flow control reduced the variation of thrust and torque to  $\pm 0.5\%$ . Concern about the possible influence of the test chamber and flow straightener on the rotor performance was



*Flow straightener material*

checked by operating the rotor in "free air" outside the chamber with zero wind (i.e., less than 0.5 fps). The rotor figure of merit measured outside agrees with that measured inside to within the measurement tolerance of 1%. Detailed flow measurements using a laser Doppler velocimeter will provide information on the generation, growth, and convection of the rotor wake vorticity.

(R. Piziali, Ext. 6096)

## Rotor Systems Flight Research

Various improvements to the Rotor System Research Aircraft (RSRA) research capability have been made during 1983. The escape system has been modified to operate at a speed of 360 knots instead of 186 knots, to accommodate the expanded RSRA envelope. The throttle system has been improved to provide a more precise throttle control. A static calibration of the Active Isolation Balance System demonstrated that the system is a successful load measurement device. A new flight computer with much greater flexibility and ease of use has been designed and is being incorporated. The flight data-processing system has been improved and will allow flight test engineers and researchers to work interactively with their flight data. A new instrumentation system to replace the obsolete FM system has been designed and is being assembled for installation

early in 1984. The static calibration facility has been upgraded to the point where calibrations require weeks rather than months to be accomplished.

The use of the tip aero acoustic test (TAAT) database of in-flight measured rotor-blade aerodynamic pressures has been demonstrated to the rotorcraft industry in a tour of the companies. Comparisons of TAAT measured blade pressures with aerodynamic codes were continued during the past year. A shake test investigation of the RSRA was completed and an extensive analytical effort was carried out to interpret the results. This culminated in a workshop with industry on dynamic-force determination methods. In a joint NASA/Army flight test effort, a pneumatic rotor blade deicing boot was successfully evaluated in icing conditions.

The RSRA is now considered a mature facility to carry out comprehensive rotor investigations. Both the Modern Technology Rotor Program and the Integrated Technology Rotor/Flight Research Rotor Program are now structured to take advantage of this capability.

(W. Snyder, Ext. 6570)



*Rotor Systems Compound Flight Research Aircraft (RSRA) over Ames-North*

## Helicopter Airborne Radar Landing Guidance

Airborne radar provides particularly attractive approach and landing guidance concepts for helicopters, since it represents a self-contained capability on board the aircraft, with a minimum of ground-based navigation facilities required. Research programs using both high-resolution airborne radar and low-resolution weather/mapping radar are in progress at Ames to develop improved helicopter airborne radar approach capability.

High-resolution radar is the most promising sensor candidate for achieving all-weather approach and landing guidance to remote sites. As an imaging sensor, it can be used for obstacle avoidance, and it has the ability to penetrate rain and fog. In a previous research program performed in cooperation with the U.S. Army, high-resolution radar imagery of typical remote-site helipads was obtained using a 95 GHz millimeter radar system. Recently, a contractor study for application of modern image enhancement techniques to this radar imagery has been completed.

The results of this study have shown image enhancement feasibility using contrast stretching and edge detection algorithms. These algorithms could be implemented in real time, thus providing the potential for enhanced image displays. Currently, another research program is under way with the objective of determining the display and control requirements necessary to operate rotary wing aircraft to selected sites in zero-visibility conditions using high-resolution radar imagery for flight guidance. A fixed-base piloted simulation was conducted at Bell Helicopter Textron under NASA contract to investigate a variety of display/control combinations. The most promising of these concepts will be further investigated in late 1984 using the Vertical Motion Simulator (VMS) at Ames. This program will define important criteria for further development of radar-derived guidance concepts.

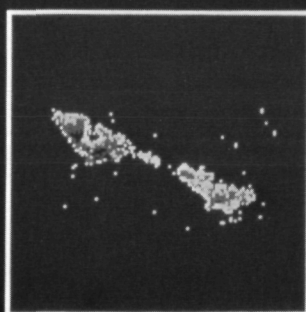
Ames has also completed another phase of research using commercial weather/mapping radar for helicopter instrument approaches to remote sites. This phase consisted of using an airborne weather radar and a transponder beacon-based ground station to provide a pilot with precision localizer and glide-slope information. An

### ENHANCEMENT ALGORITHMS

- BINARIZATION
- IMPULSE NOISE FILTER
- EDGE DETECTION
- EDGE MAPPING



**OFFSHORE OIL  
PLATFORMS**



**MILLIMETER RADAR  
RAW DATA**



**ENHANCED  
IMAGE**

*Landing-guidance image enhancement*

on-board microprocessor used radar returns from directional ground-station antennas to provide the precision guidance information. Flight tests of this system were completed in March 1983. Pilot acceptance was favorable and tracking performance was of microwave-landing-system quality. Work is being done on this concept to improve ground-station antennas for improved system navigation accuracy and to investigate localizer course-softening algorithms to reduce the close-range localizer sensitivity. Flight tests incorporating these improvements are scheduled to begin in Nov. 1983. This approach guidance concept has generated much civil and military interest, including possible use for an Air Force mission for landing tactical aircraft on battle-damaged airfields.

(G. Clary and T. Davis, Ext. 5452)

## Tilt-Rotor Preliminary Design Code and Applications

A cooperative effort between the Aeronautical Systems Branch and the Army Research and Technology Laboratories Advanced Systems Research Office at NASA Ames Research Center has resulted in a highly useful preliminary design and analysis computer program for tilt-rotor configurations. The code performs component weight estimation and predicts vehicle flight performance, including helicopter-mode hover, transitional forward flight, and airplane-mode flight. The code was used extensively in two large Army systems study efforts, the recently completed JVX Joint Technology Assessment study, and the current LHX Light Helicopter Special Workgroup study.

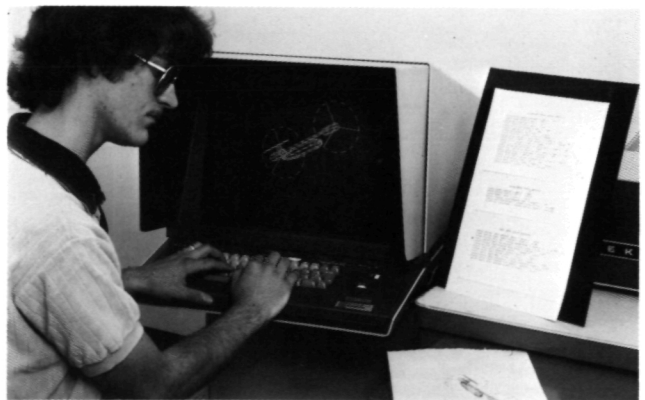
The design code takes a given set of mission requirements, engine performance characteristics, and design configuration requirements and constraints, and estimates vehicle dimensions, weights, and flight performance capabilities. The engineer can then easily and interactively change the input variables to determine optimum vehicle design or other desired vehicle characteristics. The code was originally calibrated using the NASA/Army XV-15 Tilt Rotor and included rotor performance prediction and power required versus speed requirements. Typically, an initial set of input design variables is used and the design code is run to give a first estimate of vehicle size. Using

this set of preliminary dimensions, a layout drawing is made. The resulting layout is used to define further design modifications which are in turn reentered into the design code for further iteration and refinement, resulting in an interaction design process between the engineer and the draftsman. The preliminary design code is also very useful in determining the given vehicle design sensitivity to various levels of technology, including propulsion, rotor aerodynamics, and structural design methodology. For a given design and mission/performance requirements, those technology disciplines showing the most potential for improving the configuration can be identified, and research and technology programs can be formulated.

During the JVX study, several candidate rotorcraft configurations were analyzed to perform a variety of military missions, including Marine assault missions, Army electronic warfare missions, and Air Force and Navy search and rescue missions. The results of the design code showed that the tilt-rotor configuration was the best-suited rotorcraft concept to meet all the mission requirements. During the preparation of the Request for Proposal to industry, the tilt rotor code was also used to evaluate various candidate engines to power the JVX tilt rotor and further define propulsion system requirements.

Current program development and enhancements include coupling and automating of the design layout process using computer aided design (CAD) hardware and software systems. This will enable the engineer to interact more quickly and effectively in the preliminary design process using graphic displays coupled with the tilt-rotor design code.

(J. Bowles, Ext. 5673)



*Interactive input/output graphics display coupled to tilt-rotor design code*

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## XV-15 Tilt-Rotor Research Aircraft

Due to the impact of download on the lift capacity of tilt-rotor aircraft, a series of wind-tunnel tests was conducted to quantify the download and to assess the relative download drag coefficients of various leading- and trailing-edge devices. These tests revealed that some devices can significantly reduce the download. Hardware was installed on the aircraft to permit the ailerons to act with the existing flaps as full-span flaps. This system was used in hover and on the ground tiedown stand to evaluate download. An evaluation of the XV-15's download is being conducted using the results of the wind-tunnel and hover test programs.

Under the terms of the contract with Bell Helicopter Textron, Inc., the contractor performed a number of Independent Research and Development (IR&D) test programs. The most significant of these was a flapping controller. This system is designed to minimize steady-state fore-and-aft and lateral flapping. Initial flight tests showed a reduction in the two-per-revolution frequency content of some structural loads.

Three important series of tests were conducted to prove the mission suitability of the tilt-rotor aircraft. The first involved over-water hover operations to simulate Navy Search and Rescue (SAR) operations. The aircraft performed a variety of approaches at varying heights over a pair of experienced Navy swimmers simulating downed pilots. The results of that test were highly favorable. The pilot workloads were low and the

effects of the downwash and water spray on the swimmers were lower than that experienced under helicopters presently used to conduct SAR operations. The second demonstration was a survey of downwash effects and pilot workload in simulated external loads operations. A USMC Helicopter Support Team performed normal external loads handling operations under the aircraft. They reported that they experienced conditions that were somewhat improved over CH-46 aircraft and significantly improved over CH-53 aircraft. The third military demonstration program is presently in progress at MCAS Yuma. These tests involve pilot workload in contour flight, wake surveys with OV-10 aircraft flying in the XV-15 wake field and with the XV-15 aircraft flying in the wake of a C-130 aircraft, slope-landing operations, and initial air combat maneuvering assessments flying against AH-1, A-4, and OV-10 aircraft. In preparation for a projected series of nap-of-the-Earth tests for the Army, agility tests were conducted at Ames Research Center. These tests provided data to allow definition of agility in terms of measurable parameters.

(J. Magee, Ext. 5020)

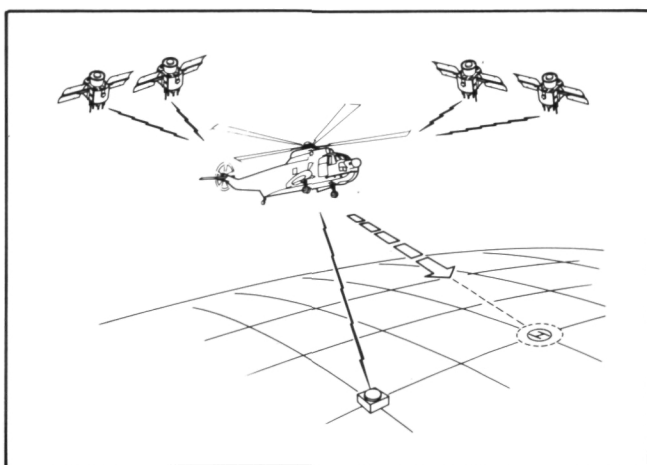
## Helicopter Satellite-Based Navigation

A NAVSTAR GPS Z-Set navigator was installed and operated in the NASA SH-3G helicopter vehicle. Results of those flight tests were analyzed and show that even with poor satellite geometry, the NAVSTAR system provides navigation accuracies much better than any other navigation system currently available and that navigation errors were not significantly affected by helicopter flight maneuvers. An input from a baro altimeter in place of a fourth satellite signal reduced the vertical error and allowed the position estimate to be independent of the satellite constellation geometry. Results of these tests and other limited flight tests reaffirmed that the position accuracy of a single-channel sequential global positioning system (GPS) navigator is sufficient to support area navigation and nonprecision approaches, but is not sufficient to meet the requirements for a CAT I precision approach.



*Hover test of XV-15 tilt-rotor aircraft over water*

NASA sponsored theoretical studies on GPS have shown that an alternative mechanization known as differential GPS can provide significant performance improvement when compared with conventional GPS, although the performance improvement is still not adequate in the vertical axis to support precision approach operations. Additional studies are under way to investigate alternative techniques to improve the vertical axis performance of a differential GPS.



*Satellite-based navigation for helicopters*

One of three candidate differential GPS concepts will be evaluated at Ames for support of helicopter precision approach operations. Hardware and software components for the airborne and ground-based system have been developed or

are under contract. Future plans include development of the remaining system components and the inflight evaluation of the concept within 24 months.

(F. Edwards, Ext. 5437)

## Full Envelope, Curved Path Approach Investigations with Rotorcraft Using the Microwave Landing System

National commitment to a microwave landing system (MLS) has led to the unique opportunity of developing procedures for expanding Instrument Flight Rules (IFR) rotorcraft operations and examining alternatives for mixing rotorcraft/fixed-wing terminal-area operations. In 1979, NASA Ames in conjunction with the FAA, completed helicopter MLS flight tests using angle-only (azimuth and elevation) data which resulted in terminal instrument procedures (TERPS) raw-data criteria for straight-in, precision approaches at 3°, 6°, and 9° glide slopes.

In 1983, a joint NASA Ames/FAA microwave landing system curved path flight test project (TERPS) was begun to develop criteria for operating helicopters along curved path approaches using a manual flight director and constant air-speed. This project resulted in the baseline formulation of curved reference flightpaths in the form

	FAA	NASA
	RNAV SEGMENT APPROACHES	CURVED PATH APPROACHES
AIR TRANSPORT	B-727 (JET RNAV) FLT TECH CTR	B-737 (ATOPS) LANGLEY
FAA AVIATION STANDARDS NATIONAL FIELD OFFICE		
HELICOPTER	S-76 (JET RNAV) FLT TECH CTR	UH-1H (V/STOLAND) AMES

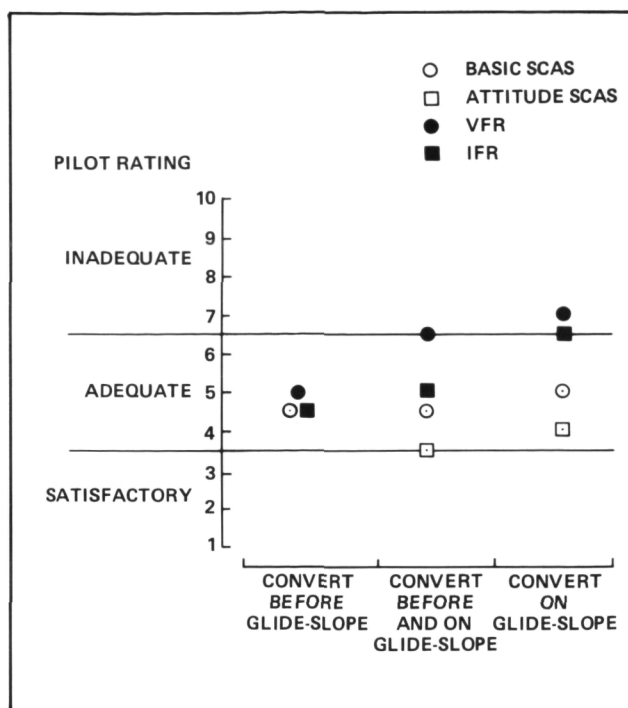
*NASA Ames/FAA full capability MLS flight tests*

of U-Turn and S-Turn precision approaches, and development of the 3-Cue flight director sensitivities and gain scheduling required to reduce pilot workload for these complex approaches. In addition, the feasibility of flying 6°, 9°, and 12° glide slope approaches was successfully demonstrated by industry, DOD, FAA, and NASA pilots, and the initial statistical database for MLS curved path approach TERPS was completed.

(J. Hamlin and H. Swenson, Ext. 5431/5469)

## Development of Certification Criteria for VTOL Aircraft, Utilizing the Tilt-Rotor Aircraft

With the potential of a transport-class military VTOL aircraft as an outcome of the JVX requirement, the development of a civil version and hence, the first civil VTOL tilt-rotor operations have become a possibility. The development by the FAA of appropriate airworthiness requirements for VTOL aircraft has therefore become necessary. Toward this end, the first ground-based simulation experiment in a projected series of investigations was conducted by NASA and the FAA in the Vertical Motion Simulator to obtain airworthiness guidelines for tilt-rotor aircraft performing terminal-area operations. A total of 96 evaluations of landing approaches for an XV-15 class tilt-rotor aircraft was obtained from three pilots, one each from NASA, the FAA, and the Civil Aviation Authority in England. Principal variables of the experiment were: (1) visual versus instrument approaches, (2) the type of stability-control augmentation, and (3) three different general conversion profiles (150 to 60 knots before glide slope; 150 to 110 knots before glide slope; 110 to 60 knots on glide slope; 150 to 60 knots, all on the glide slope). Ancillary variables included investigation of two rates of thrust-angle conversion, an interconnect of commanded thrust angle with commanded flap angle, automatic thrust tilt as a function of range, and the incorporation of three-cue flight directors on the display.



*Pilot evaluations of tilt-rotor aircraft during transition in Vertical Motion Simulator (VMS) in crosswind with moderate turbulence*

The results indicated that, for visual approaches, satisfactory performance with moderate pilot compensation was generally achievable irrespective of the conversion profile used; crosswinds and a higher level of turbulence had a noticeably degrading effect upon the baseline XV-15 SCAS but minimal influence with a higher level of augmentation, where pitch and roll attitude augmentation were incorporated. For instrument approaches, the ratings indicated that desired performance could be achieved with the attitude SCAS and the conversion profile incorporating all conversion prior to the glide slope. However, in performing some or all of the conversion on the glide slope, with no additional automation or display enhancement, the performance was degraded to adequate or marginally inadequate. It was found that the marginally inadequate performance for the profile incorporating all the conversion on the glide slope could be improved to the satisfactory level by adding automatic thrust tilt and three-cue flight directors.

(J. Lebacqz, Ext. 5272)

# Influence of Sideslip on the Flight Dynamics of Rotorcraft in Steep Turns at Low Speeds

A set of efficient algorithms has been developed to permit a systematic examination of statics and flight dynamics of aircraft in various levels of uncoordinated high- $g$  turning maneuvers. These algorithms were applied to a tilt-rotor aircraft and two single-rotor helicopters to investigate the influence of sideslip on the flight dynamics of these rotorcraft in steep turns at low speeds. The results show that the aircraft trim attitudes in uncoordinated high- $g$  turns can be grossly altered from those for coordinated flight (side force up to  $\pm 0.1 g$ ), and that the dynamic stability of these rotorcraft is relatively insensitive in these maneuvers. However, the coupling between the longitudinal and the lateral-directional motions is strong, and it becomes stronger as the sideslip increases.

In addition, the individual effects of the aerodynamic, kinematic, and inertial coupling on a hingeless-rotor helicopter in steep turns were assessed. The results show that the aerodynamic derivatives affect primarily the stability characteristics of the high-frequency dynamic modes; the terms owing to the presence of the aircraft angular rates exert their greatest influence on the stability of the low-frequency modes. The inertial coupling alone or the kinematic coupling resulting

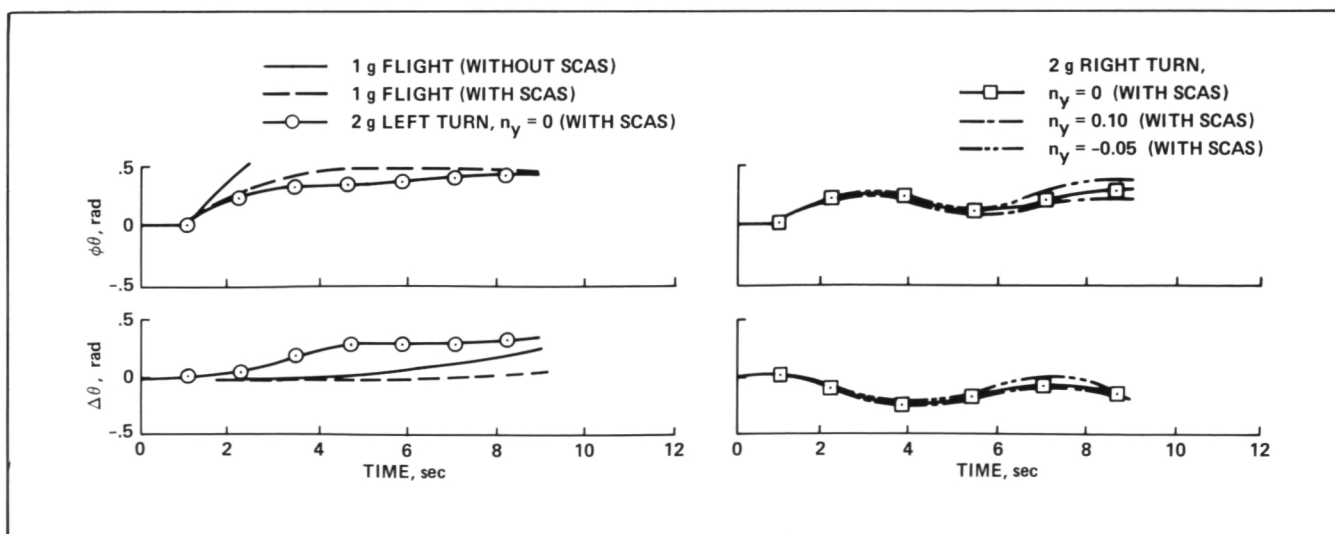
from the aircraft attitude and sideslip have only a slight influence on the flight dynamics of the helicopter in high- $g$  turns.

Examination of the effect of uncoordinated, high- $g$  turns on the performance of a sophisticated stability and control augmentation system (SCAS) indicates that the aircraft response with the SCAS on can degrade as sideslip increases. The influence of sideslip, however, is less drastic than that of either load factor or turn direction reported previously in this series of studies.

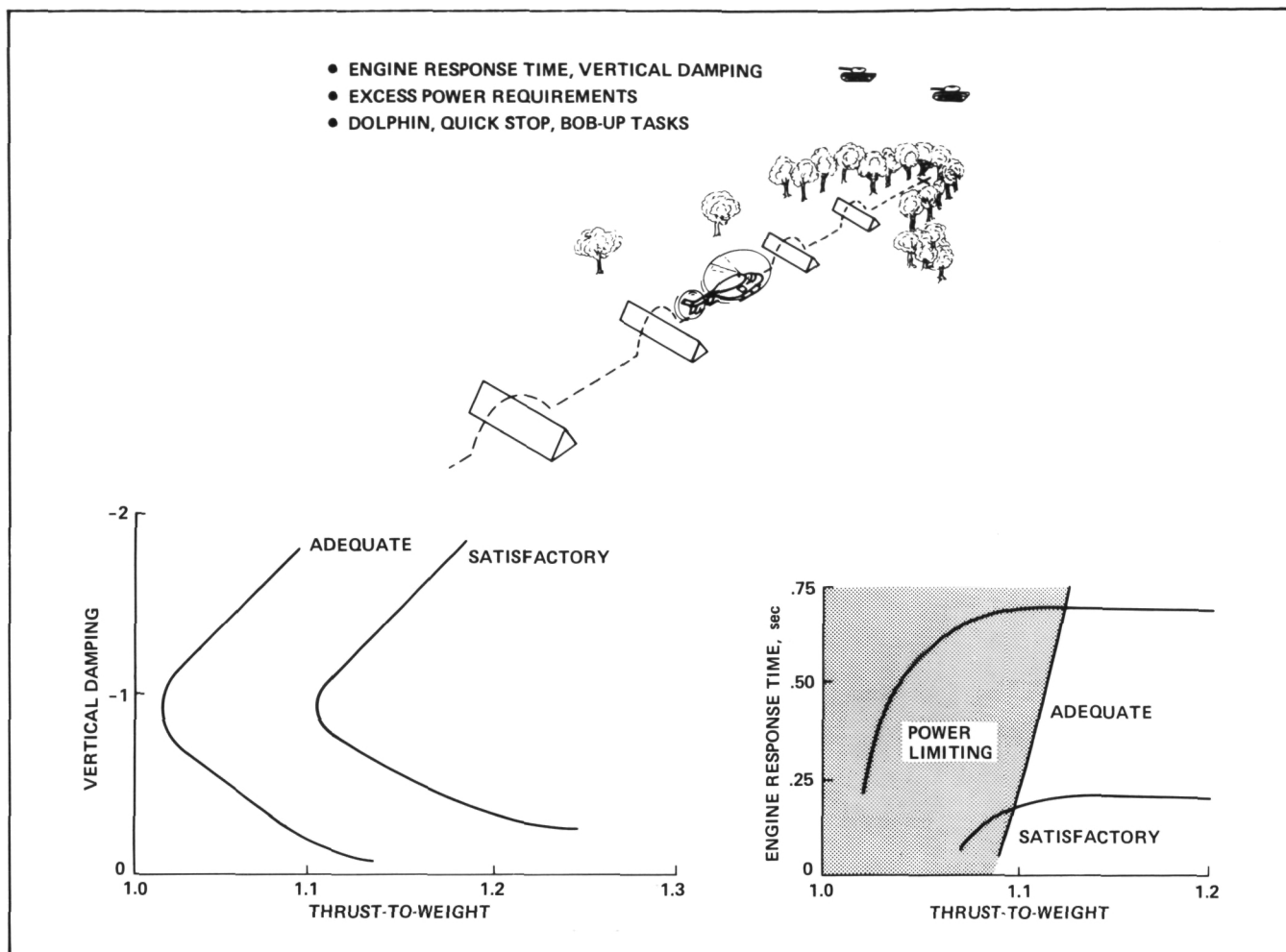
(R. Chen, Ext. 5008)

## Effects of Engine and Thrust-Response Characteristics on Handling Qualities of Rotorcraft

The effects of thrust-response characteristics on helicopter handling qualities have until recently remained largely undefined. A multi-phase program is being conducted to study, in a generic sense and through ground simulation, the effects of engine response, rotor inertia, rpm control, excess power, and vertical damping on specific maneuvers including nap-of-the-Earth (NOE) operations. To date, three moving-base, piloted simulation studies have been conducted. In addition, the frequency characteristics of the helicopter thrust response, which set it apart



Effect of load factor, turn direction, and uncoordinated turns on control response



*Effects of engine dynamics on helicopter flying qualities*

from other VTOL types, was explored. The power-system response is affected by both engine response and the level of rotor inertia. However, results indicate that with unlimited power, variations in engine response can have a significant effect on pilot rating, whereas changes in rotor inertia generally do not. The results also show that any pilot interaction required to maintain proper rpm control can significantly degrade handling qualities. Data for variations in vertical damping collective sensitivity have been compared with existing handling-qualities specifications (MIL-F-83300 and AGARD 577), and show a need for a higher minimum for damping and sensitivity for the bob-up task. Results for cases of limited power have been obtained.

(L. Corliss and C. Blanken, Ext. 6269/5836)

## Computer Simulation Programs for Multipropulsor Hybrid Aircraft Studies

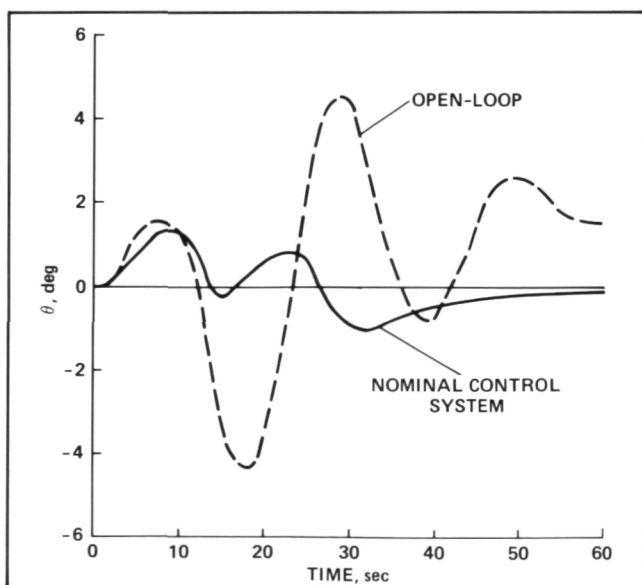
A comprehensive nonlinear, non-real-time simulation computer program, intended for the study of multirotor aircraft configurations, has been completed under a NASA contract. The program, called HYBRDS, is a flexible program which will simulate the dynamics of aircraft consisting of any combination of buoyant hull/fuselages, various tail configurations, and up to four each of rotors, propellers, and jet thrusters. The stability and control characteristics and the performance of the vehicle over the entire flight envelope can be analyzed for the vehicle alone, or for the vehicle plus a slung payload. Analysis of

the unpowered vehicle at mooring can also be performed. The three major functions of this program are: (1) calculation of trim conditions for performance estimates and control requirements; (2) calculation of linearized stability derivatives about selected trim conditions; and (3) forward integration in time of the vehicle state variables in response to control and/or aerodynamic inputs. Evaluation of the configuration dynamics can be performed open or closed loop to provide data for determining the vehicles' handling qualities, for use in control system design, and for structural design. The data can also be used in a manned simulation to further evaluate the vehicles' characteristics.

This program was delivered with five volumes of documentation consisting of an executive summary, a technical manual, a user's guide, a programmer's manual, and appendices to the user's guide.

Pre-flight analyses using HYBRDS provided valuable data in planning the Navy/Coast Guard Patrol Airship Concept Evaluation program to evaluate the Airship Industries' "Skyship 500." Data were taken to define the basic dynamics of the Skyship 500. These data will be used to validate the aerodynamic modeling scheme and the dynamic analysis used in HYBRDS. Preliminary results show that the vehicle's basic dynamic modes are well predicted. HYBRDS has been used to evaluate the effects of turbulence on the buoyant quad rotor concept.

(P. Gelhausen, Ext. 5888)



*Pitch attitude response to vertical gust of buoyant quad-rotor vehicle*

## Digital Flight Control System Verification Laboratory (DFCSVL)

The DFCSVL, developed under a joint NASA/FAA program, has been used to investigate the effectiveness of stress testing flight software to improve the verification process and to explore an integrated approach to the verification of digital flight control systems.

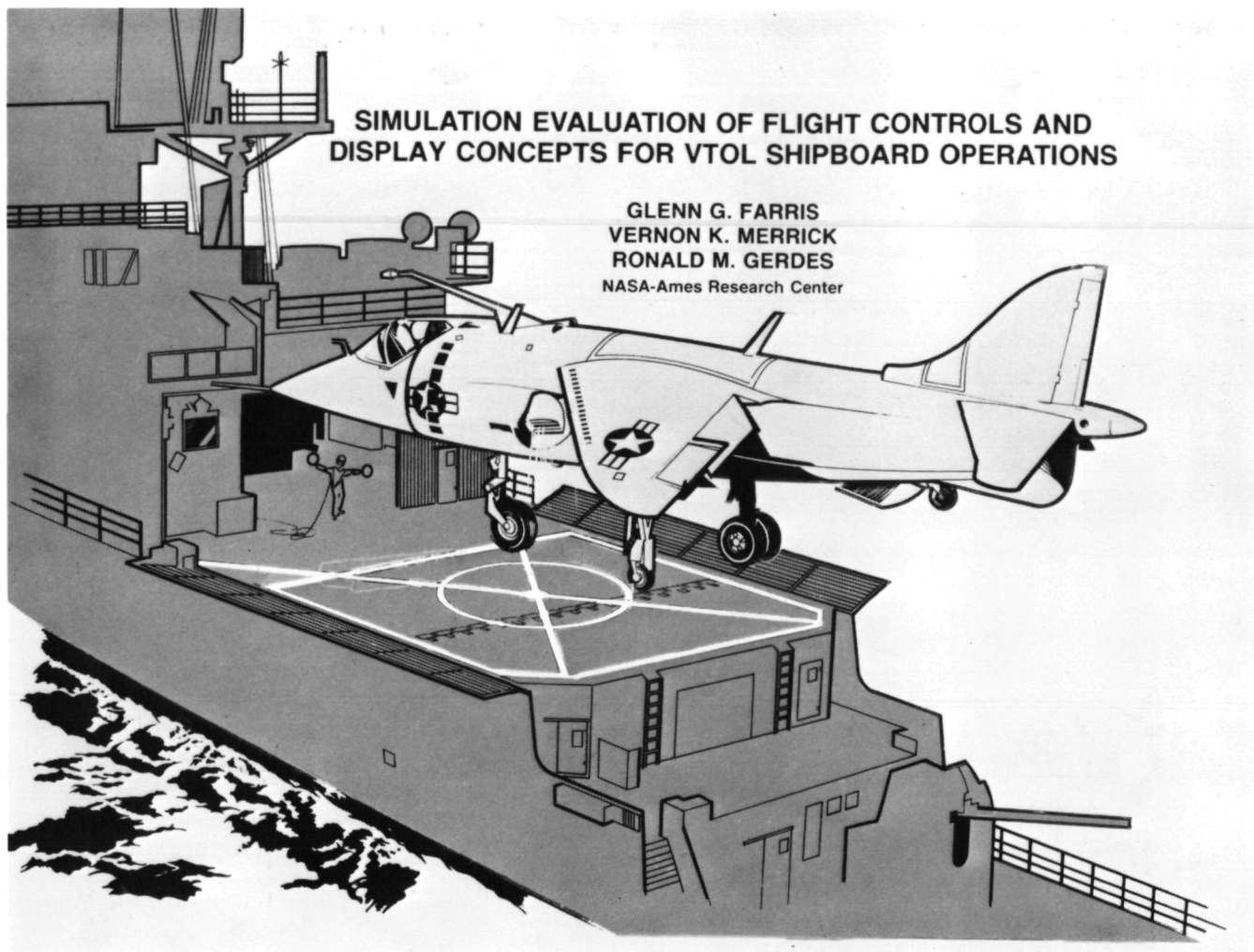
Stress testing, developed under a grant with Stanford University, is a technique for dynamically testing DFCS software on a module-by-module basis. Each test module is repetitively executed faster than real time with a wide-ranging input sequence. Outputs of the test module are compared with outputs generated by an alternative but simplified module for the same input data. Differences between the two sets of output data indicate possible software errors. The results of this investigation are being presented at the 5th Digital Avionics Systems Conference in Seattle. Future work will focus on automating this technique and assessing its overall effectiveness to detect errors seeded into flight software representative of commercial applications.

The integrated application of reliability prediction analysis with failure effects and system simulator methods to establish the airworthiness of flight-critical DFCS was demonstrated by the Lockheed-Georgia Company under sponsorship of the FAA. This approach used fault tree and reliability prediction techniques augmented by detailed failure modes and effects analysis below the circuit card level. Hardware fault insertion was manually conducted in the DFCSVL to confirm predicted results.

(D. Doane and J. Saito, Ext. 5440/5048)

## STOVL Flight Control/Cockpit Display Concepts

Research is being conducted to determine the operational capability of various flight control system and cockpit display concepts. Operational



## SIMULATION EVALUATION OF FLIGHT CONTROLS AND DISPLAY CONCEPTS FOR VTOL SHIPBOARD OPERATIONS

GLENN G. FARRIS  
VERNON K. MERRICK  
RONALD M. GERDES  
NASA-Ames Research Center

tasks concentrate on transition, approach, and hover to a vertical landing aboard ship. Attitude and velocity control systems are being evaluated, with concentration on comparing simple thrust management systems with more complex acceleration and velocity command controls. Cockpit displays, appropriate to the particular mode of control are also being assessed. Research is focused on head-up display (HUD) formats of the situation-director type and of the perspective display type. These supplement external cues with conformal presentations or provide guidance information that is analogous to real-world visual cues. Experiments with these controls and displays are being conducted in a fixed-base cockpit flight simulation and in large moving-base simulators.

A simulation was performed on the Ames Vertical Motion Simulator (VMS) using a four-window computer-generated-image display to investigate control/display trade-offs in hovering

and landing operations on a destroyer. A total of 12 control systems and 7 display formats were evaluated using an AV-8A aircraft model with an engine model provided by Lewis Research Center. This experiment showed that a HUD is vital in high sea states, that translational velocity command is by far the most effective control system, but that, with some additional attention to HUD symbology, attitude command coupled with a nozzle nudger and vertical damping may be acceptable even in sea state 6. Assessments of control power required for shipboard landing seem to support the conjecture that they are dependent on the degree of control sophistication. This work will continue as data from future simulations become available. Work is continuing on improved head-up and head-down display formats, and on improved pilot controls based on the results of this experiment. Further evaluation of control utilization will also be made.

(V. Merrick and G. Farris, Ext. 6194/6002)

## Quiet Short-Haul Research Aircraft

The Quiet Short-Haul Research Aircraft (QSRA) was chosen by NASA for flight presentation and display at the 35th Paris Air Show, Le Bourget, France, May 27 through June 5, 1983, to demonstrate its high-performance/short takeoff and landing capabilities and low-speed flying qualities. The characteristics of the QSRA without leading-edge flaps outboard of the engine nacelles were evaluated in preparation for the ferry flight to the Paris Air Show. The clean wing QSRA had an improvement in range of as much as 15%; however, the stall speed increased to 80 knots, with stall occurring at approximately  $14^\circ$  as predicted by wind-tunnel data.

A second NASA/Navy Upper Surface Blowing/Circulation Control Wing (USB/CCW) test was accomplished in late August, at the Ames V/STOL static test site. This joint effort between the Navy's David W. Taylor Naval Ship Research and Development Center and Ames was performed in order to evaluate the effect of an improved, Navy designed, CCW flap on the static turning performance of a full-scale USB airplane. During the two-week test period, the effects of flap radius, jet characteristics, and wing fences were evaluated, and all test objectives were met successfully.

A research control, display, and guidance system was installed in the QSRA to investigate the

operating characteristics of powered-lift STOL aircraft. Experiments planned include an evaluation of control-authority requirements; development of highly augmented, system-control margin requirements; establishment of landing-performance methods; and development of controls and display formats for carrier landings and tactical STOL aircraft. Emphasis in the QSRA control displays and guidance research program is on the approach and landing tasks where the selection of operating modes must require only a very small portion of the pilot's workload.

Equipment installed in the QSRA consists of (a) programmable displays that include pilot and copilot color electronic attitude-director indicators (EADI), a head-up display (HUD), and a moving map malfunction display (MFD); (b) an automatic throttle; (c) a landing-approach area navigation capability; and (d) a flight-control digital computer to permit the development and evaluation of flight-director control laws, display formats, stability and command-augmentation system control laws, and energy management guidance and control laws. A mode-select panel and pilot and copilot flight-mode annunciators have been designed that incorporate the pilot-assist modes found in recent and conventional jet transports along with new selection features for a microwave-landing system and for a minimum-fuel, energy-management guidance system.

(D. Watson and D. Riddle, Ext. 5826/6085)



*QSRA at the Paris Air Show*

## Fault-Tolerant Control Systems

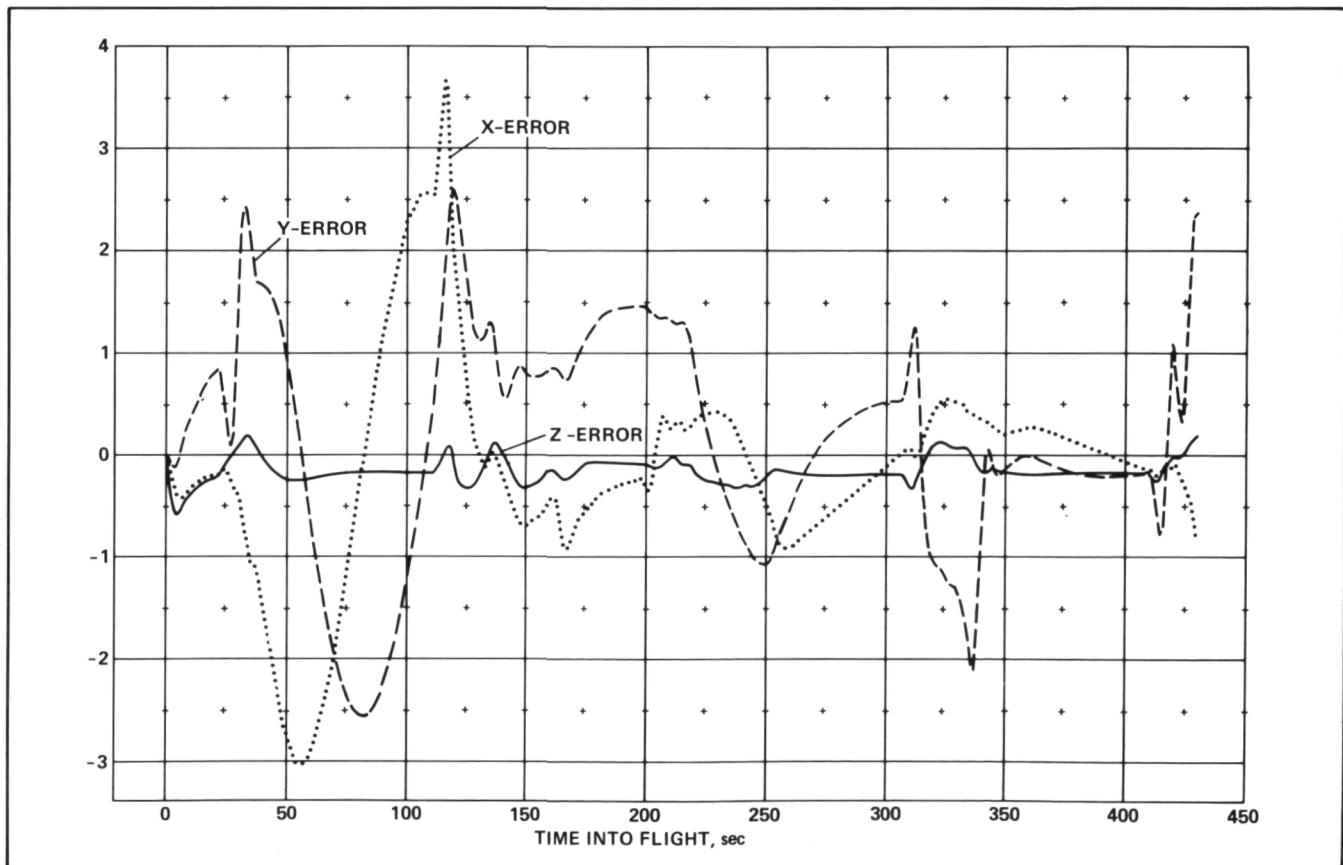
An unusual fault-tolerant control system concept called Redundant, Asynchronous Microprocessor System (RAMPS) is currently being investigated at Ames Research Center in conjunction with researchers from the University of Southern Colorado and the City University of New York. Most fault-tolerant control concepts are implemented using synchronization. The RAMPS concept uses asynchronously coupled microcomputers to achieve ultra-reliable real-time control of aircraft, effectively drawing together the fields of modern control theory, microprocessor and actuator technology, and digital communications, and bonding them into a coherent concept. Preliminary results from flight simulations using actual (not modeled) system elements have shown that the asynchronously coupled RAMPS can effectively hold aircraft to a prescribed course and correctly annunciate failures as they occur. The benefits derived from asynchronous fault-tolerant systems can be significant. The

most important are the autonomy of system elements, and the significant improvement in reliability over alternative systems (approaching  $10^{-12}$  failures per hour over 10 hr of flight).

(L. Webster, Ext. 5941)

## Automated Flow Management Concepts

The air-traffic-control system stands at the threshold of a massive change that will cost billions of dollars and take over a decade to complete. The central theme of this change is the extensive use of computers to automate complex decision processes on the ground and in the air. At Ames, research in air traffic control is concentrating on concepts and computer algorithms for automating air traffic flow management in a complex terminal area. This program is being conducted in cooperation with the FAA.



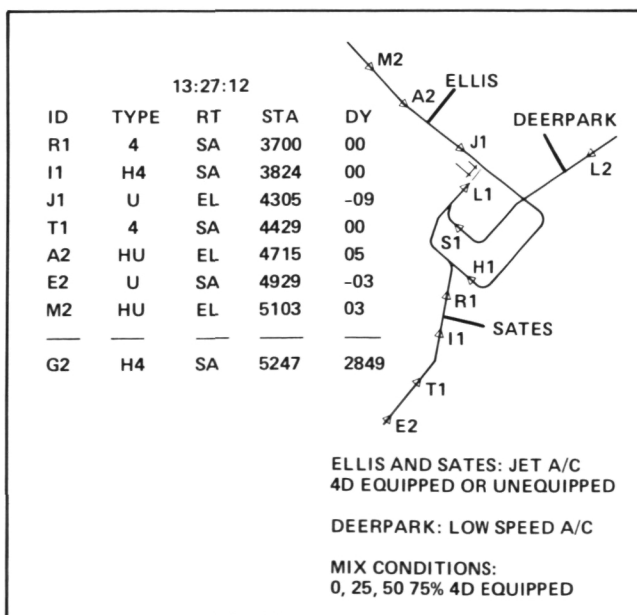
*RAMPS position tracking error (ft)*

This year an air-traffic-control simulation study focused on the problem of time-scheduling a mix of flight-management-equipped and unequipped aircraft. The percentage of equipped aircraft, which will have data links to the ground system and accurate time control four-dimensional guidance, will rise gradually over the next decade. The study attempted to determine if automated air-traffic-control procedures can be developed with the intelligence to handle efficiently a mix of differently equipped aircraft types. The ability of automated systems to control a complex traffic mix is an essential design requirement.

Simulation results showed that controllers could learn to use the highly predictable flight-paths of the four-dimensional equipped aircraft as guideposts to vector unequipped aircraft to their assigned landing slots. As the percentage of four-dimensional equipped aircraft in the traffic was increased from 0% to 75%, the total number of controller clearances decreased steadily. Most importantly, the decrease in the number of clearances was also observed for the unequipped aircraft. Thus, it appears that the procedures developed allow even unequipped aircraft to benefit from the presence of the equipped aircraft.

Studies are now in progress to develop interactive scheduling procedures and ground-computer based algorithms to predict landing times of unequipped aircraft.

(H. Erzberger and L. Tobias, Ext. 5450)



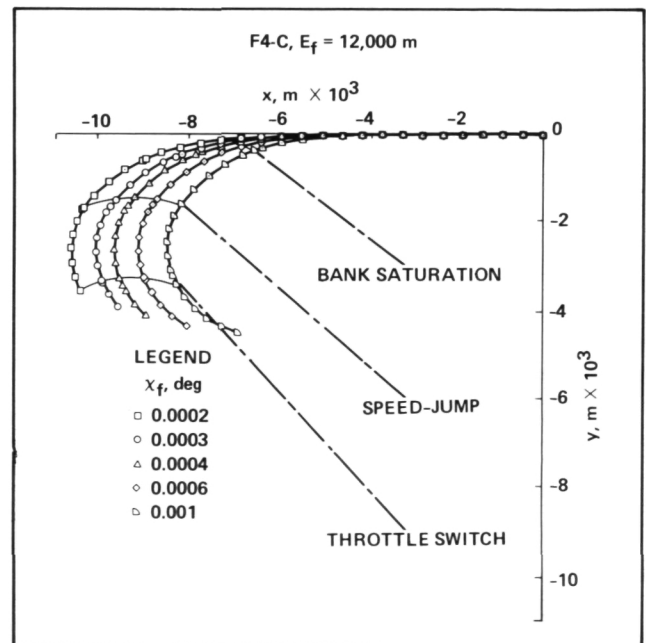
Approach controller display used in simulation

## Flightpath Optimization of High-Performance Aircraft

Because high-performance aircraft are capable of rapid, complex maneuvers and have complex mission objectives, flightpath optimization of such aircraft is extremely difficult and they continue to be largely controlled manually by pilots. The combination of two relatively new theories, differential games and singular perturbations, promises to make possible the development of guidance laws for optimal maneuvering of high-performance aircraft.

Recent research has resulted in feedback optimal guidance laws for accurately modeled aircraft maneuvering in a horizontal plane and in a simplified algorithm for three-dimensional target interception. Current research is extending these results to obtain optimum guidance laws for three-dimensional air-to-air combat. The approach is to solve an energy-state differential game in feedback form and then to use singular perturbation methods to account for the neglected dynamics. The algorithms will be capable of implementation in real time and will be tested in future simulations.

(M. Ardema, Ext. 5433)



Projection of energy-state extremals in horizontal plane

## All-Weather Shipboard Operations

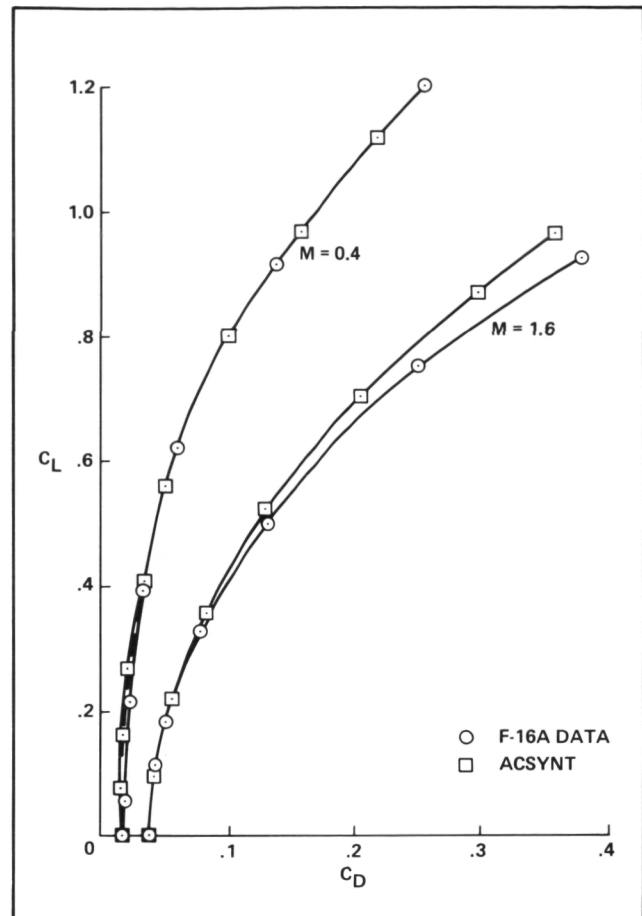
The present capability for operating helicopters or V/STOL aircraft from small ships is limited by low visibility, ship motion, and airwake turbulence. Operational capability is further reduced by the high pilot workload caused by aircraft-guidance, control, and display limitations. To improve ship-landing capability, ground-based simulation experiments have been conducted on the Vertical Motion Simulator at Ames to evaluate guidance, control, and display concepts for use in helicopter shipboard operations. A Kaman SH-2F helicopter operating off a Spruance-class destroyer was simulated. Four different hovering flight control law concepts of varying complexity, a head-up and a helmet-mounted display, and a deck-motion lull/swell forecasting guidance algorithm were evaluated.

The simulator results indicated that to achieve at least adequate performance, attitude-command control compensation was required regardless of the display used. For best performance, especially in high sea states, a velocity-command, ship-relative position-hold control system was desired. For the ship-landing task, the pilots were able to determine lull opportunities visually. However, use of the lull/swell forecasting guidance algorithm resulted in significantly shortened hover times prior to the landing.

(C. Paulk, Ext. 5440)

## Performance Comparison Between the F-16A and the Powered Lift E-7 Aircraft

An Ames study comparing the mission performance of the General Dynamics Corp. short takeoff and vertical landing (STOVL) conceptual design E-7 relative to the F-16A has been completed. The Ames-developed conceptual/preliminary aircraft design synthesis computer program ACSYNT was the primary tool for all design evaluations. The figure indicates the correlation with F-16A aerodynamic performance using ACSYNT. A STOVL configuration has inherently fewer performance penalties than a



*Comparison between actual versus predicted aerodynamic performance of the General Dynamics F-16A*

V/STOL design because vertical takeoff, a compromising design factor, is not a consideration. Although the F-16A is an Air Force fighter and the E-7 has been designed for Navy fighter/attack missions, the design requirements are similar enough that a meaningful indication of the impact of the STOVL requirement and mission performance has been possible.

The E-7 configuration features a single turbofan engine, deflecting nozzle for the core exhaust, and a longitudinally arrayed ejector system which augments fan thrust 63%. Compared with the F-16A, the E-7 has 110% more wing planform area, 76% more internal fuel capacity, 40% more thrust, and 14% higher takeoff weight for equal payload weight. The STOVL requirement gives an 83% decrease in takeoff distance and a 100% decrease in landing distance relative to the F-16A.

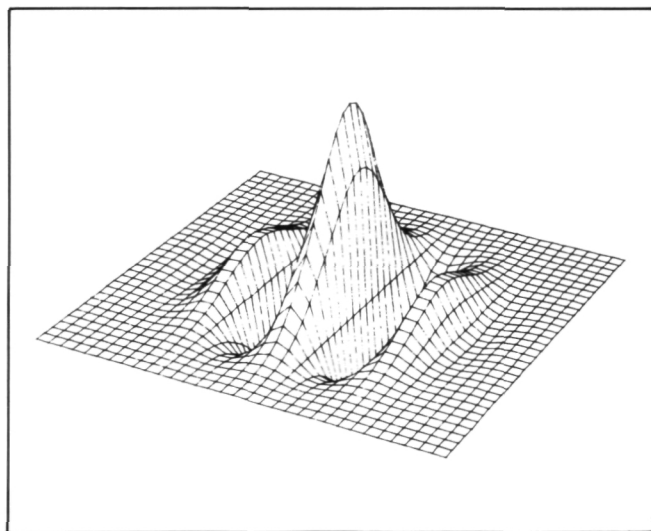
The analysis has shown that, compared with the E-7, the F-16A has 20% higher maximum Mach number, 20% lower transonic acceleration

time, and 25% higher specific excess power in steady flight. However, the E-7 has 50-60% higher mission radii and an equal sustained load factor capability. In summary, the E-7 is highly capable for air-to-ground attack missions and average for air-to-air missions, whereas the reverse is true for the F-16A.

(G. Kidwell, Ext. 5886)

## Human Vision Model

The intelligent design of visual displays for flight simulators, aircraft cockpits, and computer terminals requires extensive knowledge about human visual perception. A computational model has been developed that will provide this knowledge in a compact and usable form. When complete, the model will provide an estimate of the visibility of an arbitrary pattern of arbitrary color which may move or change over time in arbitrary ways. The model will also indicate the discrimination of one display element from another, and the influence of one display element on other display elements.



*Gabor function with a bandwidth of one octave*

The current version of the model decomposes the visual image into a collection of Gabor functions with a bandwidth of one octave that differ in spatial frequency, orientation, and location. The scale of the decomposition increases linearly

with distance from the fovea. The resulting transform is then processed by an optimal Bayesian classifier. Laboratory experiments indicate that the model gives excellent predictions of the visibility of static achromatic images.

(A. Watson and A. Ahumada, Ext. 6110/5421)

## The Aviation Safety Reporting System

One of the responsibilities associated with NASA's safety research activities is the Aviation Safety Reporting System, an incident reporting program designed to identify issues and hazards in the national aviation system. The program is administered by NASA for the Federal Aviation Administration under a management and funding agreement initiated in 1975.

Incident reporting has proven to be a logical and effective supplement to established accident investigation procedures and other system monitoring techniques. Whereas incidents occur with predictable regularity, and always leave the participants in a position to help investigators if they so choose, accidents often preclude post-event interaction with the flight crew members.

The Aviation Safety Reporting System (ASRS) is a voluntary, confidential, nonpunitive incident reporting program. Because of these characteristics it has succeeded in obtaining information marked by honest self-appraisal of pilot and controller performance as reported by the performers themselves. As a consequence, much of the information in the ASRS database is unique and represents a valuable insight into human performance and aviation system issues.

In the course of its safety research activities, the Aviation Safety Reporting System has produced 14 program reports, published 51 issues of CALLBACK — the ASRS monthly safety bulletin, released 11 research reports dealing with specific safety topics, and responded to 517 requests for specific incident data. Responses to specific data requests have included air-traffic-control system data for the FAA, military-civilian traffic mix information for the Department of Defense, and site-specific operational data for the National Transportation Safety Board's accident

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investigations. This accounting illustrates the fact that the ASRS is capable of converting raw incident data into safety information for both short-term and long-term use by the FAA, NASA, NTSB, and other elements of the aviation community. The product of the ASRS is available in the form of issue-specific unidentified data for use in research conducted outside the ASRS organization, research reports produced by the ASRS staff, bulletins regarding possible safety problems, and education publications designed for use by training facilities and individuals involved in the aviation system.

(W. Reynard, Ext. 6467)

## **Synthetic Speech for a Helicopter Radar Threat Warning System**

During the past several years there has been increasing interest in the use of automatic speech recognition and synthetic speech technology for in-cockpit use. Potentially, such technology would allow a quasi-natural "dialogue" to take place between the pilot and highly automated systems that is envisioned for use in advanced civil and military aircraft systems. A particularly promising application area is in low-altitude helicopter missions, where the pilot is required to concentrate visually on the outside environment for navigation and obstacle avoidance.

Research was recently completed to define the linguistic characteristics and message display rules for a synthetic speech system being incorporated into an upgraded version of the U.S. Army and U.S. Marines radar threat warning system (APR-39A XE-1). Working with the Army's Aircraft Survival Equipment (ASE) Project Manager, and the prime contractor (Dalmo Victor Operations), the new radar warning system was simulated and made to respond to computer-generated threats in a nap-of-the-Earth (NOE) mission environment. Warning system failures were simulated in the visual, auditory, and combined modalities, and the pilot's ability to survive (i.e., avoid enemy weapons) in this hostile environment was evaluated under each condition.

The study was conducted by a combined team of researchers from NASA, the Army, and

Psycho-Linguistic Research Associates. The results confirm clearly the value and pilot enthusiasm for a speech display system under the intense maneuvering conditions of the NOE mission. Virtually all of the seven Army and Marine pilots tested found that they could function adequately with a speech display only, and many indicated a preference for the speech display over a conventional (visual) panel display. As is often the case with high-technology applications, novel system integration issues were also revealed, such as the need to synchronize the display of visual and auditory information to avoid pilot confusion, the importance of carefully training the pilot to understand the accent of computer-generated speech, and the frequency and speed parameters that work best in this operational environment.

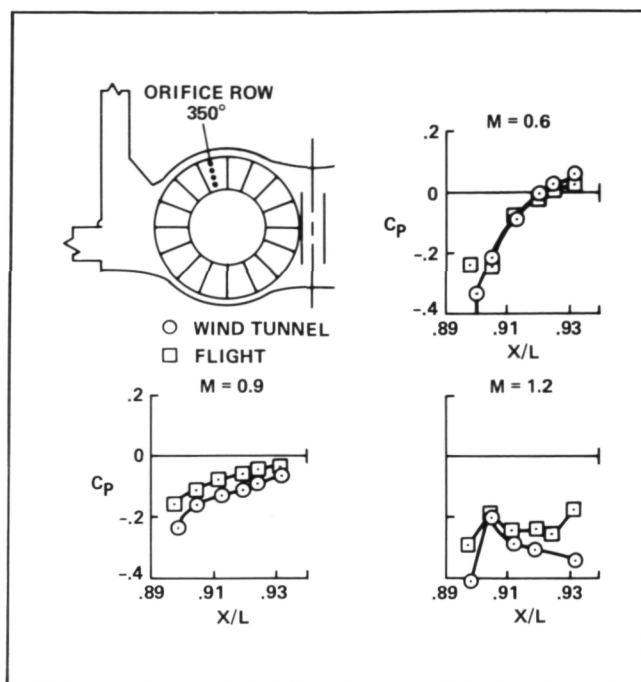
(E. Huff, Ext. 5734)

## **Correlation of Transonic Nozzle Drag Over a Wide Reynolds Number Range**

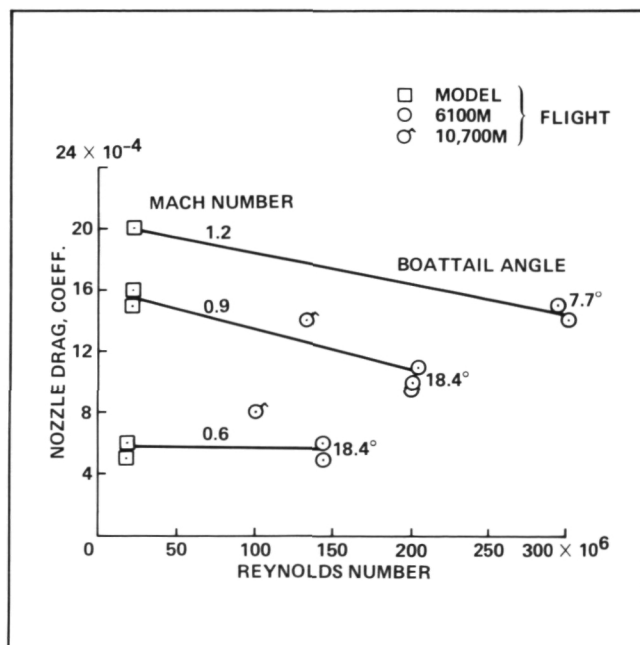
The Ames and Langley Research Centers have recently completed an experimental program involving model and flight tests of a twin-jet F-15 fighter to investigate the effects of flow interference on the propulsion system installation. For the nozzle-airframe region, the model data were obtained in the Langley 16-Foot Transonic Tunnel, and on the F-15 in flight.

To ensure that the comparisons between model and full scale would be believable, the model configuration was modified to simulate the airplane closely, and the instrumentation was located in the same locations on the model and airplane. Test conditions in the tunnel and in flight were closely coordinated; however, there was a large disparity in the Reynolds number test ranges. The model data were obtained at a Reynolds number of about 20 million, whereas the flight data were obtained over a Reynolds number range of 80 million to about 300 million. These values are based on the length of the fuselage.

An example of the data that have been obtained is shown here. One figure displays a



Nozzle pressure distributions measured in wind tunnel and in flight



Effect of Reynolds number and compressibility on nozzle drag

comparison between the pressure distributions on one of the eight instrumented rows of the left nozzle for Mach 0.6, 0.9, and 1.2. Whereas at Mach 0.6 there is good agreement, the effects of compressibility and Reynolds number at the higher Mach numbers indicate the relatively poor

simulation of the full-scale flight performance in the wind tunnel. The second figure illustrates the commensurate reductions in nozzle drag in flight relative to those measured in the wind tunnel.

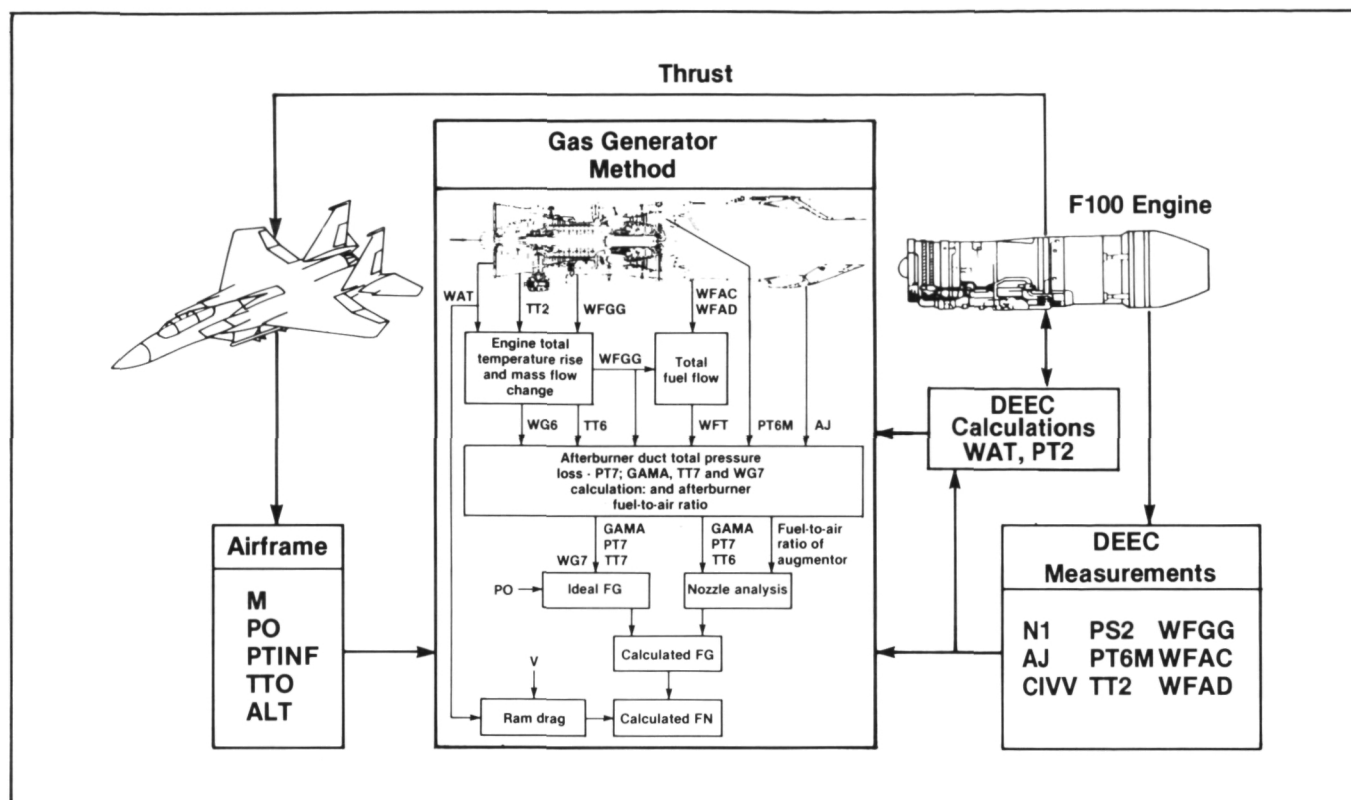
(J. Nugent, Dryden Ext. 3688)

## Real-Time In-Flight Thrust Measurement

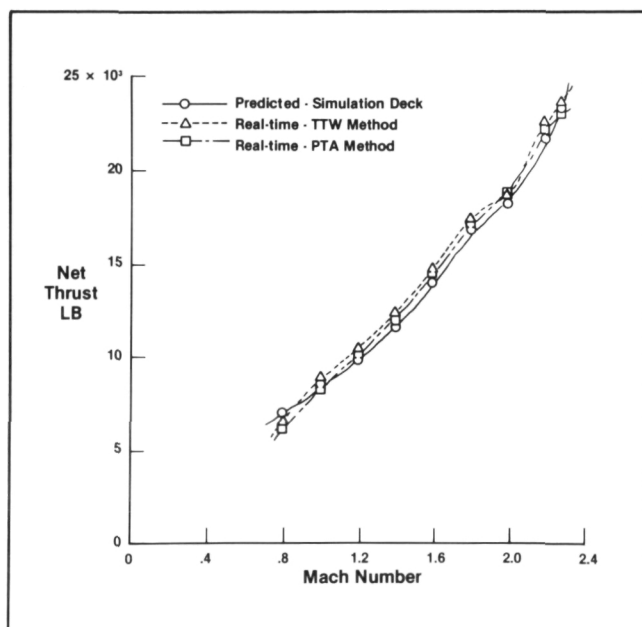
In-flight calculation of thrust in real time is being made on an F-15 airplane. The Ames Dryden F-15 is powered by F100 afterburning turbofan engines, equipped with digital electronic engine control (DEEC) systems. The calculation of thrust uses a version of the Pratt & Whitney aircraft in-flight thrust deck, intended for post-flight analysis, but modified to run in real time. The real-time thrust deck uses the gas generator method, in which a combination of measured engine/airframe parameters and mathematical models is used to calculate gross thrust. A schematic of the calculation procedure has been made. The mathematical models are derived from sea level static tests and altitude test facilities. Two different gas generator calculations are performed; the total pressure-area method uses four variables, and the total temperature-weight flow method uses five variables. Both methods use empirical data to correct from ideal to actual gross thrust. No special instrumentation is required on the engines because the DEEC system already measures all necessary engine parameters with continuous output. These real-time in-flight measurements have allowed major advancements in flight test productivity and efficiency and have helped significantly in analyzing the performance of the DEEC/F100 EMD engine.

A comparison of predicted net thrust and two real-time values of calculated net thrust have been made. Predicted thrust is calculated with the engine simulation deck using test day conditions and ram air recovery factors as inputs. There is a 2% to 5% difference between predicted and real-time values.

The ultimate goal of real-time performance analysis is to calculate standard day performance, including lift and drag in real time, to a very high accuracy. This data could then be compared with



Real-time in-flight thrust calculation



Predicted versus calculated net thrust; maximum power at 40,000 ft

## Hot Wire Anemometers for Boundary-Layer Transition Detection Flight

The Ames Dryden Flight Research Facility has conducted preliminary development of a technique to use hot wire anemometers for boundary-layer transition detection in flight. Four hot wire anemometers were placed at 50%, 55%, 60%, and 65% chord on the right wing of a PIK 20E motorized sailplane. Output from the four sensors was recorded on a simple cassette tape recorder.

Power spectral density analysis was performed on the output from gages known to be located in laminar and turbulent portions of the boundary layer. Distinct differences in both level and bandwidth exist between laminar and turbulent flow.

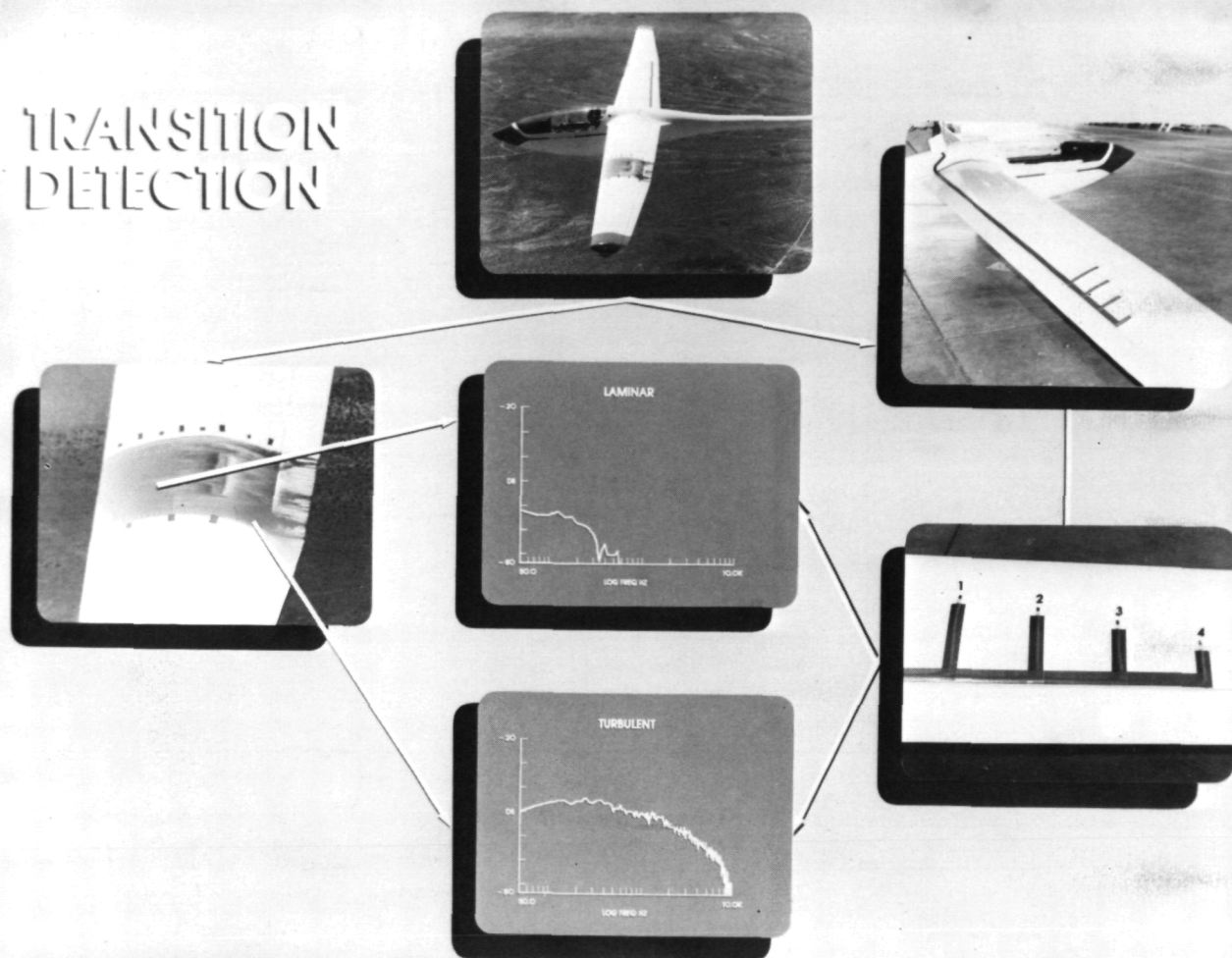
This testing is supporting the development of the technique for detection of transition in high-speed flight.

(J. Johnson, Dryden Ext. 1520)

wind-tunnel and theoretical values, and could provide a base for upcoming projects such as HIDEK and X-29A.

(L. Myers, Dryden Ext. 3698)

## TRANSITION DETECTION



*Detection of boundary-layer transition on wing of sailplane*

## Controlled Deep-Stall Experiment

A Schweizer 1-36 sailplane has been modified and flown in a controlled manner to angles of attack as high as  $75^\circ$ . Modifications include an all-movable horizontal tail that can be positioned at angles from  $0^\circ$  to  $70^\circ$ . In the deep-stall flight condition, the wing becomes totally stalled while the horizontal tail remains more or less aligned with the flightpath. Five controlled deep-stall flights have been flown to obtain data at high angles of attack.

Research objectives are to demonstrate the feasibility of manned controlled deep-stall flight, correlate flight-determined aerodynamics with wind-tunnel data, and compare the full-scale flight characteristics with 1/4-scale free-flight

results. Current effort is directed toward obtaining aerodynamic data and refining the piloting techniques needed to safely transition to, maneuver in, and recover from deep-stall flight.

(A. Sim, Dryden Ext. 3716)

## F-104 Aircraft Flight Test Fixture

Two research efforts were completed during 1983: (1) the response of samples of advanced thermal protection system (TPS) materials to typical launch airloads and (2) a real-time pilot display system, used for trajectory guidance.

Two flexible TPS materials were tested, Felt Reusable Surface Insulation (FRSI) and Advanced Flexible Reusable Surface Insulation



*Sample of Advanced Thermal-Protection System (TPS) tested in flight on F-104 aircraft "stub-wing" fixture*

(AFRSI), which are both certified for use on the Shuttle orbiter. Five TPS configurations were evaluated in a flow field which was representative of relatively flat areas on the Shuttle without secondary flows. There were no failures noted during post-flight inspections of the TPS materials that were exposed to air loads 40% higher than the design launch air loads.

The Ames-Dryden Flight Research Facility has developed a system which allows commands to be telemetered (up-linked) in real time from a ground-based computer to either cockpit displays or autopilot commands. This system allows not only particular flight trajectories to be flown as a matter of routine, but stabilized point data to be obtained very efficiently.

(R. Meyer, Dryden Ext. 3707)



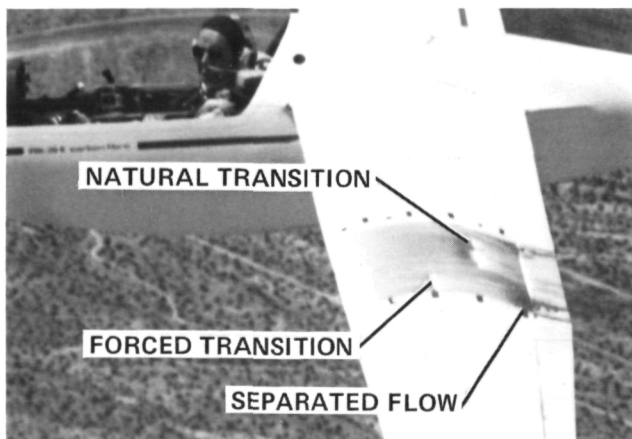
*Trajectory guidance display in cockpit of F-104 aircraft*

## Use of Oil for In-Flight Surface Flow Visualization

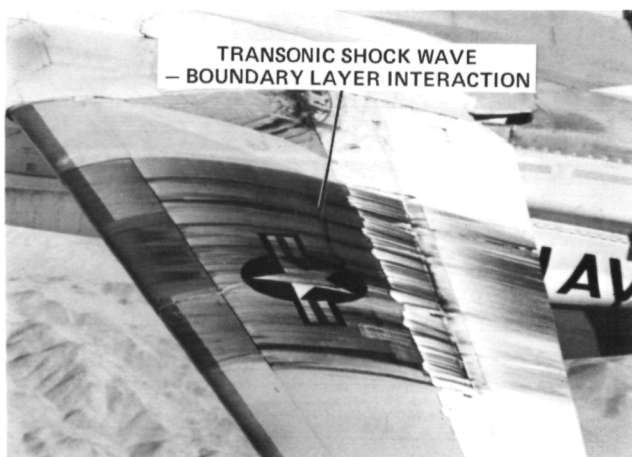
Oil has been applied to aircraft surfaces to indicate aerodynamic characteristics such as boundary-layer transition, and regions of separated flow during flight. The technique is identical to the surface oil-flow coating procedures used in testing wind-tunnel models.

Examples are shown from low-speed tests of a PIK-20E sailplane and high-speed tests with an F-14 fighter. Successful results have been obtained at altitudes up to 25,000 ft and at speeds from 45 knots to Mach 1.25. The only limitation is that the oils currently used become too viscous to respond adequately to the flow at altitudes above about 25,000 ft, because of the low temperature.

(R. Curry and R. Meyer, Dryden Ext. 3714/3707)



*PIK-20E oil flow tests, 95 KIAS, -4° flap deflection*



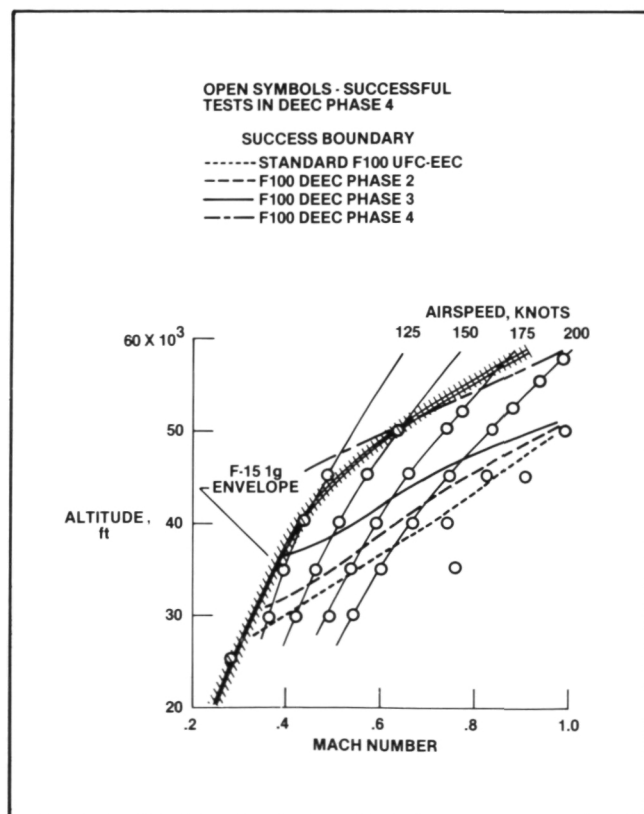
*F-14 oil flow tests, Mach 0.86, 20° wing sweep*

# Digital Electronic Engine Control

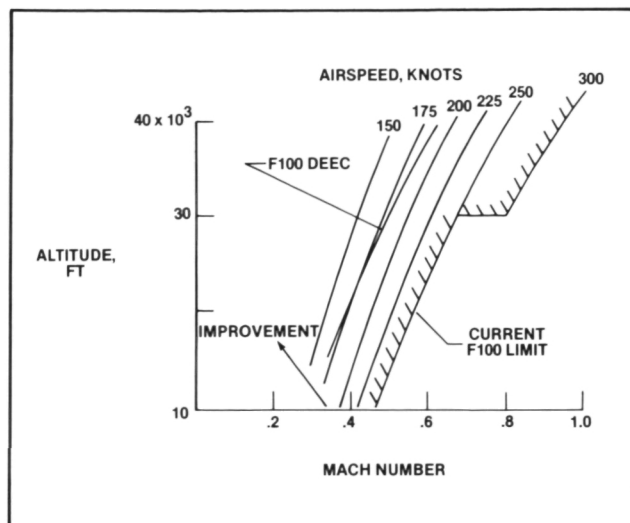
An evaluation of a digital electronic engine control (DEEC) on an F100 engine in an F-15 airplane has recently been completed. The DEEC is a full-authority, single-channel digital control with selected input-output redundancy and a simple hydromechanical backup control. With the DEEC, major improvements in performance and operability were achieved in a program of 30 flights.

The DEEC, with its closed-loop control capability, is capable of automatically compensating for engine-to-engine variations, engine degradation, control tolerances, and fuel variations, and it also eliminates the need to periodically retrim the engine control system. This no-trim feature would result in a cost savings of \$150 million if it were installed on one-half of the F-16 fleet.

The DEEC also has a closed-loop airstart capability which allows airstarts at airspeeds that are 75 knots lower than the standard F100 engine. In addition, the airstart sequence is completely automatic, and no pilot attention is required.



DEEC idle-to-maximum transients



DEEC spooldown airstarts

Afterburner transient capability was evaluated in almost 1000 tests, mostly in the high-altitude/low-air-speed part of the flight envelope. In the earlier phases of the DEEC testing, the afterburner operation was no better than the standard F100 engine. Using the flight results and altitude facility tests, Ames-Dryden and the engine manufacturer developed improved software and hardware. During the last phase of the flight evaluation all idle-to-maximum throttle transients were successful, giving an increased altitude capability of 15,000 ft over the standard F100 engine.

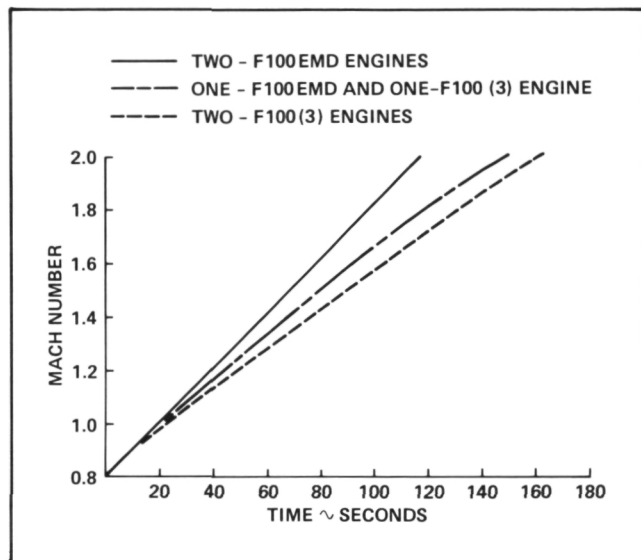
The Air Force has decided to proceed with full-scale development of the DEEC system, based in part on the results of the F-15 flight evaluation. This could eventually lead to production for both F-15 and F-16 airplanes.

(F. Burcham, Dryden Ext. 3126)

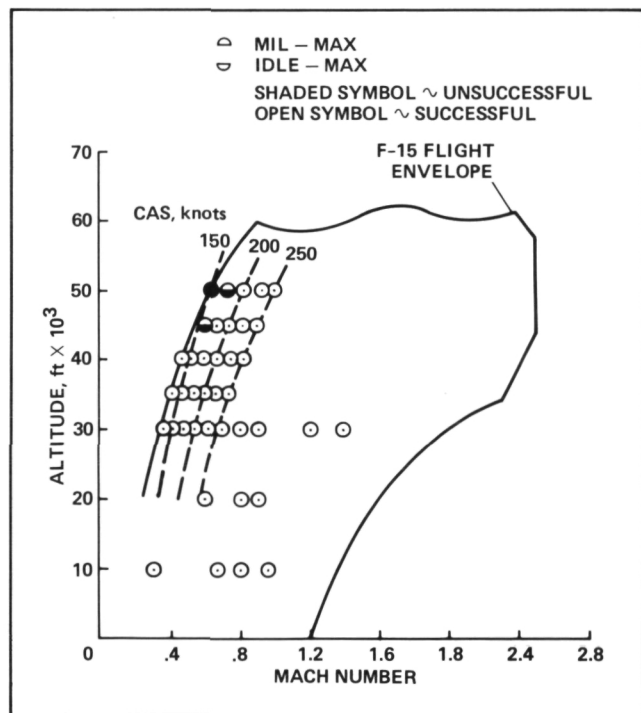
## F-15/F100 Engine Model Derivative Flight Evaluation

The value of an early flight evaluation of a new engine has been demonstrated. The F100 engine model derivative (EMD) is an improved version of the F100 engine that powers the F-15 and F-16 airplanes. The F100 EMD features a bigger fan, higher-temperature turbine, a digital control system, and a redesigned 16-segment augmentor, resulting in a 15% to 20% increase in thrust. The flight evaluation has consisted of investigations of the performance (thrust, fuel flow, airflow)

and operability (transient response, airstarting) in the Ames-Dryden F-15 airplane. The performance of the F100 EMD has been excellent. Comparisons have been made of the acceleration of the F-15 with two standard F100 engines, one F100 and one F100 EMD engine, and two F100 EMD engines. The time to reach Mach 2 is reduced by 37% with the two F100 EMD engines.



Maximum power accelerations of F-15 aircraft with F100 and F100 EMD engines; standard day at 40,000 ft



Augmentor transients of F100 EMD engine in F-15 aircraft

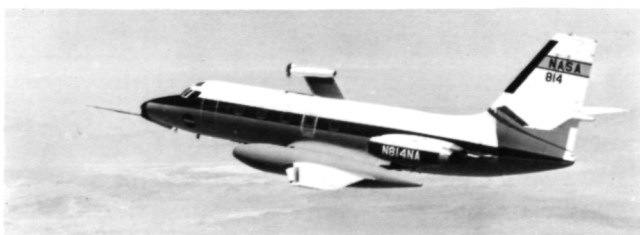
Several anomalies have been discovered in the operability investigation. The throttle response for formation flying was poor and required a software change to the control system. The augmentor operation was initially limited by failures to light at high-altitude/low-air-speed conditions and a hardware change was made to eliminate the problem. The sensitivity of the PS2 sensor to inlet distortion has not agreed with ground-test results. Also, nonrecoverable stalls occurred in flight at very low airspeeds and high altitudes, whereas previous altitude facility tests had not indicated any stall problems. Special tests were run at the Lewis Research Center on their F100 EMD research engine, but the cold temperatures experienced in flight could not be duplicated. Clearly, these last two anomalies could not have been found without flight tests. Identifying these problems at a relatively early point in engine development greatly simplifies the task of correcting the problems. Even with these problems, the transient performance of the F100 EMD is impressive.

(L. Myers, Dryden Ext. 3698)

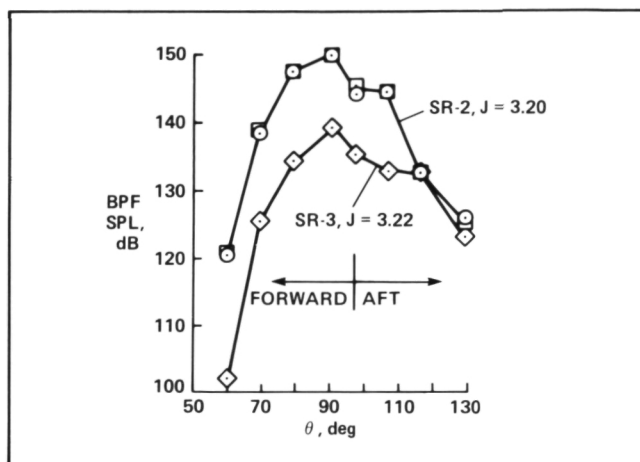
## Advanced Turboprop Flight Research

Flight tests of three high-speed propellers have been conducted as part of the NASA advanced design turboprop program. These tests were conducted to investigate near-field acoustic characteristics of the various propellers. The results are needed to define near-field acoustics for assisting in the design of larger-scale propellers.

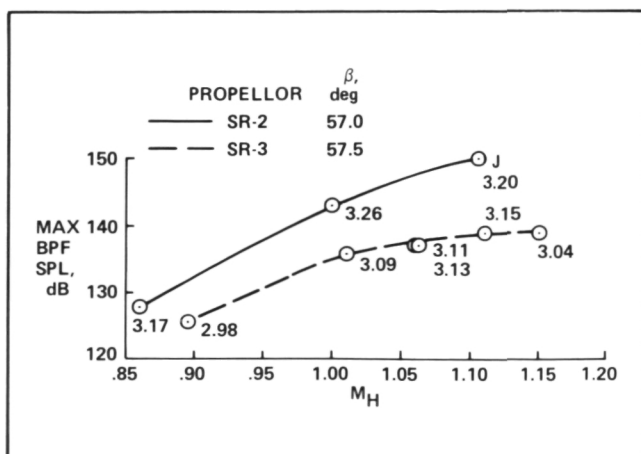
The Ames-Dryden JetStar airplane was modified for the advanced-design propeller experiment by mounting a pylon on top of the fuselage and installing an air-turbine drive motor. An array of flush-mounted microphones was located on the fuselage under the propeller for making the acoustic measurements. Boundary-layer rakes were installed on the fuselage under the propeller plane to determine the flow field in the boundary layer. An airspeed boom was also flown at the propeller location to accurately determine the Mach number and flow angularity. For later acoustic flights, a microphone boom was mounted above the propeller to acquire acoustic data free of fuselage boundary-layer effects.



(a) JetStar modified for advanced-design propeller experiment



(b) Comparison between blade-passage frequency sound-pressure levels around fuselage beneath SR-2 and SR-3 propellers; SR-2 blade angle is  $57^\circ$ ; and SR-3 is  $57.5^\circ$ ; airplane Mach = 0.79; blade helical Mach = 1.11



(c) Maximum blade passage frequencies and pressure levels for SR-2 and SR-3 propellers at 30,000 ft

Three advanced-design propellers (SR-2, SR-3, and SR-6) have been flight-tested. Acoustic data analysis of the three propellers is being undertaken at three NASA Centers.

Shown here are comparisons of the blade passage frequency sound pressure levels of the SR-2 and SR-3 propellers. The airplane Mach number was 0.79 and the blade helical Mach number was 1.11, which is near the blade design condition. The tone levels forward of the propellers are at least 10 dB lower for SR-3, whereas aft of the propellers these differences are not as great.

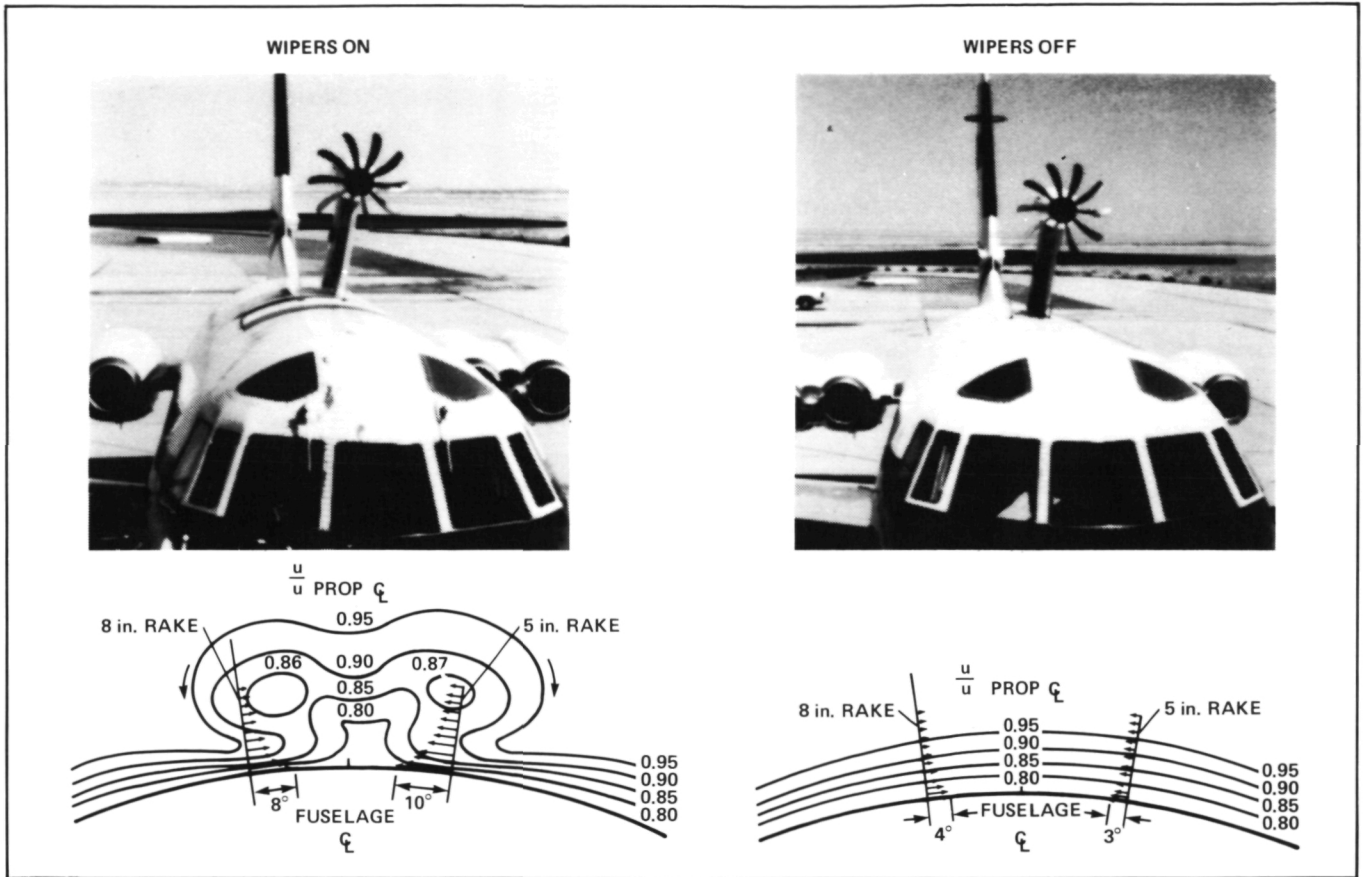
The maximum tone levels, as a function of tip Mach number, have been demonstrated. At the low tip Mach numbers, SR-2 is 6 dB higher than SR-3 and increases to 11 dB at the higher tip Mach numbers, which are near design conditions.

(P. Lasagna and K. Mackall, Dryden Ext. 3691/3697)

## Flow Field Survey for JetStar Acoustic Tests

A flow field survey was conducted in conjunction with the advanced design turboprop (ADP) acoustic program on the Ames-Dryden JetStar airplane. The boundary-layer characteristics beneath the propeller were required for a more complete understanding of how the acoustic waves from the propeller operating at supersonic top speed propagate to the fuselage-mounted microphones. Surface static ports and two boundary-layer rakes were installed. The initial boundary-layer measurements showed evidence of an unusual flow disturbance. Inspection of the airplane suggested that the windshield wipers were generating vortices that were affecting the flow field 4.5 m downstream. The removal of the windshield wipers yielded a conventional boundary-layer profile.

(K. Walsh, Dryden Ext. 3686)

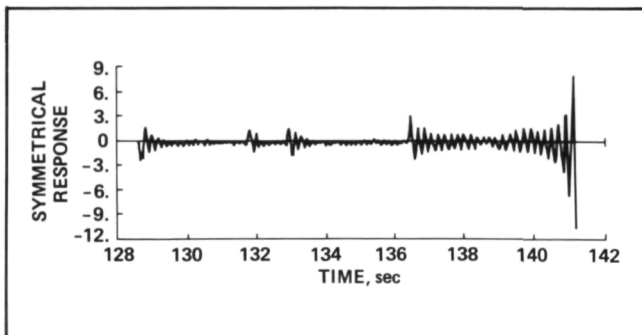


Boundary-layer measurements beneath plane of propeller,  $M = 0.8$  and 30,000 ft

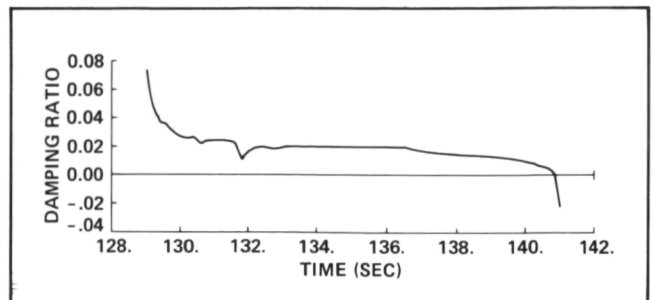
## Real-Time Flutter Analysis

Real-time analysis of flutter test maneuvers can contribute significantly to improved safety for flight tests of new and modified aircraft, reduce flight test time, and aid in envelope expansion. The real-time analysis must be reliable and accurate, and should require only minimal real-time inputs from the operator/analyst. Development and evaluation of prototype estimation algorithms were performed under contract by Integrated Systems Incorporated. The algorithms

developed are suitable for vibration analysis of known excitation inputs and randomly forced (turbulence) excitation. Practical problems associated with colored sensor noise and higher-order dynamics are automatically compensated for by overspecifying the size of the model. A general conclusion in the case of random excitation is that sufficient turbulence must be present to produce a signal-to-noise ratio of approximately 10 for estimation of the damping ratio. Low-level known excitation can significantly enhance frequency and damping estimates when the signal-to-noise ratio is low. The recursive least squares



Flutter incident response of DAST ARW-1 wing



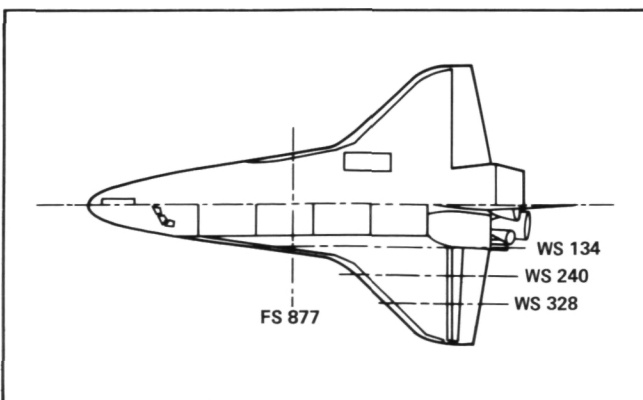
Estimated damping of the flutter mode of DAST ARW-1 wing

algorithm has been applied to DAST ARW-1 flight data covering approximately the 10 sec prior to flutter encounter. The flight test time history and the estimated damping ratio derived from the recursive algorithm show the decrease in damping that occurred as the flutter condition was encountered. Practical implementation of a real-time flutter-analysis capability based on the methods described will significantly aid in flight-test flutter clearance.

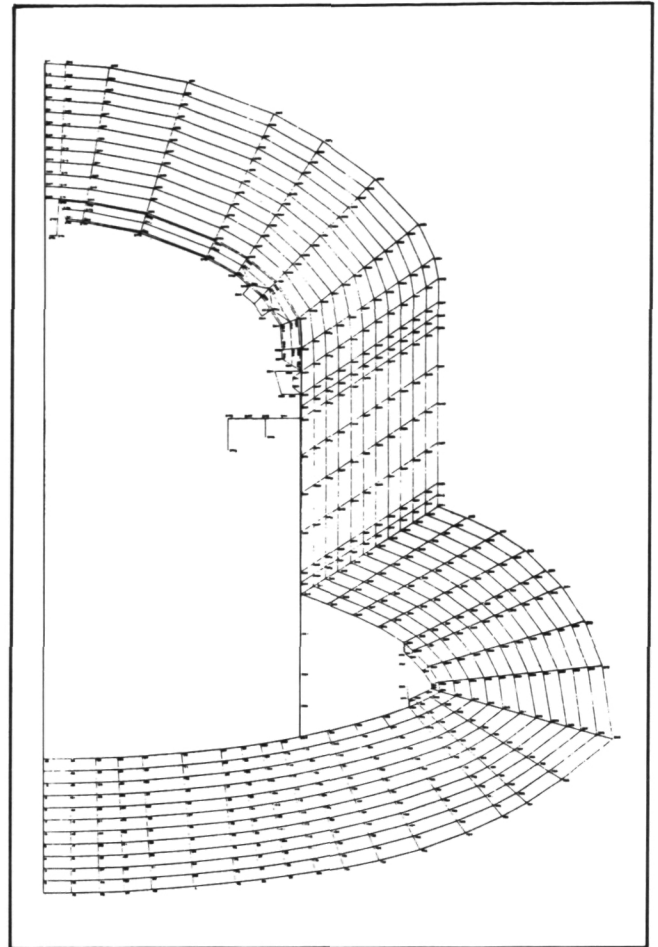
(G. Gilyard, Dryden Ext. 3724)

## Hot Structures Research

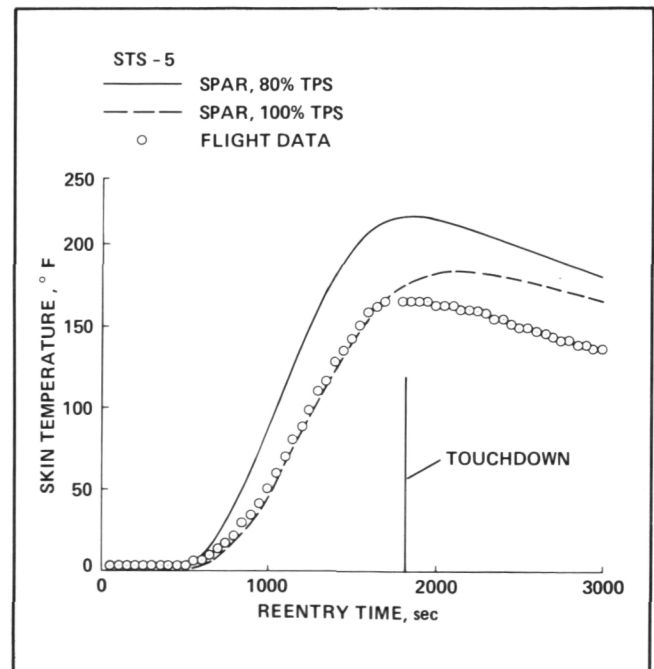
A capability for the analyses of surface heating and internal structural temperatures is a key element in the determination of structural loads and stresses in high-speed aircraft and spacecraft. Detailed Structure Performance and Resizing (SPAR) finite element computer program models of three Shuttle wing stations (134, 240, and 328) and one fuselage station (877) have been generated to provide heat transfer analyses to support strain gage load measurements during reentry. The Shuttle STS-5 flight provided a more complete set of flight data than the prior four flights for comparison with analyses. The actual STS-5 flight profile data were used in the calculations of the aerodynamic heat inputs to the SPAR thermal models. The SPAR model was set up for two thermal protection system (TPS) thicknesses: (1) 80% effective thicknesses for high-temperature reusable surface insulation and low-temperature to account for tile gap heating and (2) 100% TPS thickness everywhere. Depending



*Cross-sections of Shuttle-Orbiter wing where thermal analysis was performed*



*SPAR thermal model at fuselage station 877 of Shuttle Orbiter*



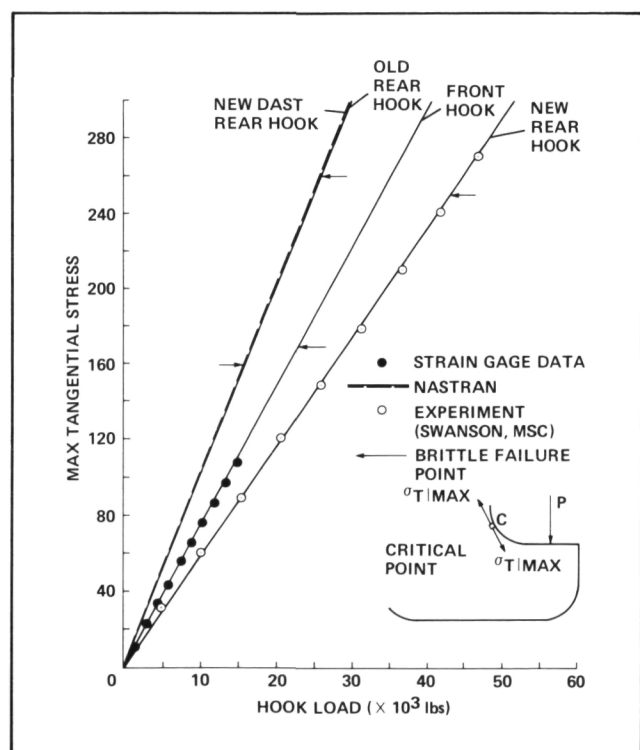
*Time history of lower fuselage skin temperature*

upon the location, the measured structural temperatures correlated with either the 100% or 80% TPS thickness calculations. Forced convective cooling near the end of the reentry flight was shown to have a negligible effect on the structural temperatures. However, the internal natural convection in the fuselage after landing has a considerable effect on the structural temperatures.

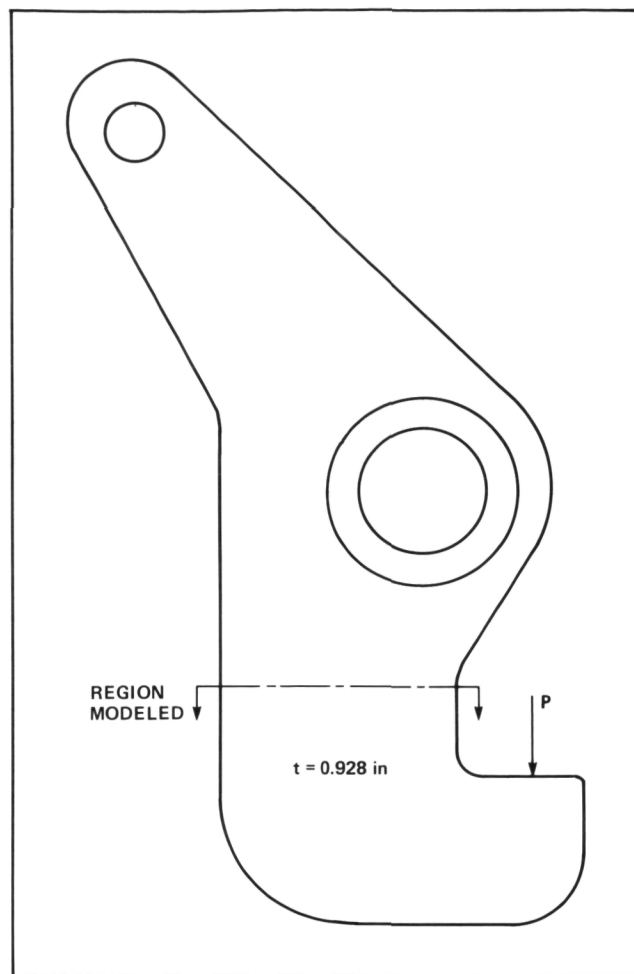
(W. Ko, Dryden Ext. 3581)

## Stress Analysis of Airborne Launch System Hooks

A detailed finite element stress analysis was performed on four different steel hooks that are part of the airborne launch system in the Ames-Dryden B-52 aircraft. The analysis was performed in support of the Space Shuttle Solid Rocket Booster (SRB) parachute system test program. A simulated SRB called the Drop Test vehicle (DTV) was built that would provide a load of 49,000 lb for testing one of the SRB's three main parachutes. The DTV was to be carried aloft to



Maximum tangential stresses with application of load at critical points in hooks



B-52 pylon rear hook

35,000 ft and released. This would be the heaviest load carried by the B-52 hooks since the last X-15 flight tests of many years ago. A structural failure of the rear hooks due to stress corrosion, which occurred during ground towing of the B-52 with the DTV, demonstrated the need for a reevaluation of the stress field present in the hooks. A NASTRAN finite element model of the hook was generated using PATRAN.

A fracture mechanics study of the broken surfaces of the failed hook was performed. In the study, the stress present at the point of failure was calculated using a measurement of the size of the corrosion crack. That stress agreed well with the finite element analysis results for the old hook design. The results from the detailed stress analysis were compared with elementary strength of materials calculations. These comparisons showed that the stress concentration factors for the new hook designs were lower than for the older hook designs, the primary objective of redesigning the hooks.

A static test of one of the redesigned aft hooks was performed. The strain gauge readings obtained were compared with predicted values from the analysis, providing further confidence in the predicted results.

(W. Ko, Dryden Ext. 3581)

## HiMAT Aeroelastic Analysis

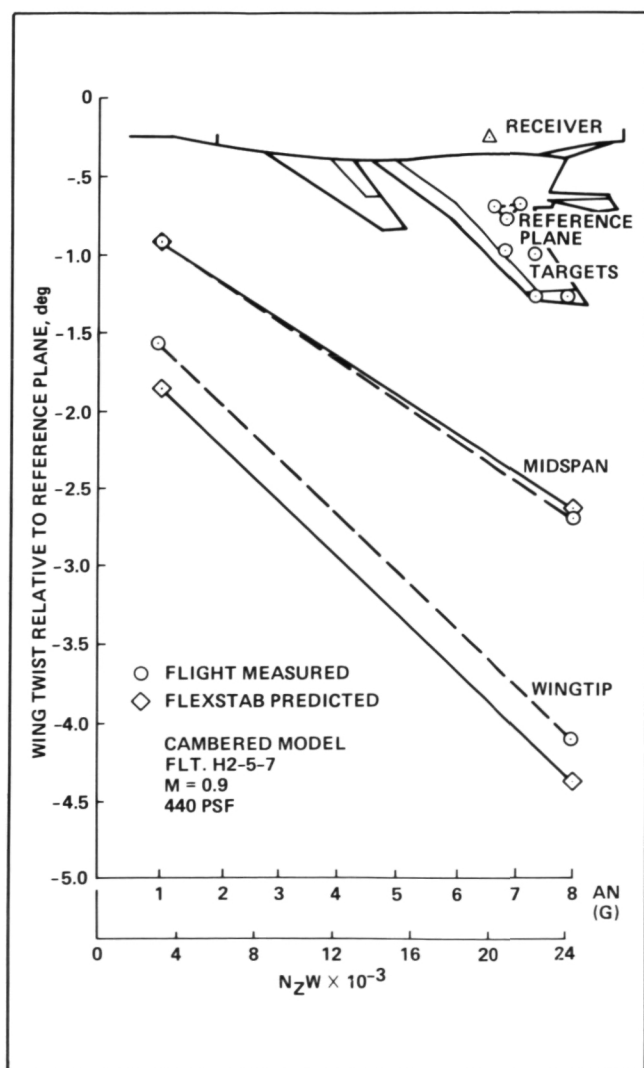
Structural loads and deflections of the HiMAT aircraft were predicted for various flight cases and compared with flight-measured data. This analysis was performed using NASTRAN, FLEXSTAB, and several smaller computer programs.

NASTRAN, a versatile finite element computer program, was used to model the HiMAT structure

and to generate a representative flexibility matrix. A distributed load set was applied within NASTRAN, and the outputs of the structural deflections were compared with corresponding measured ground test deflections to verify the accuracy of the structural model. The FLEXSTAB program system was used to create the aerodynamic geometry model; compute panel pressures over the entire aero model; and in conjunction with the NASTRAN flexibility matrix, to predict displacements of each aero model panel centroid. A follow-on program was used to integrate the panel pressures with various strain gauge stations and thereby calculate predicted flight air loads.

Strain gauges provided the measured structural flight loads, and a comparison between predicted and measured wing structural loads was made. Deflections of the wing and canard were measured in real time by the HiMAT Electro-Optical Flight Deflection Measurement System developed and tested at Ames-Dryden. Values of wing twist were derived from the measured displacements.

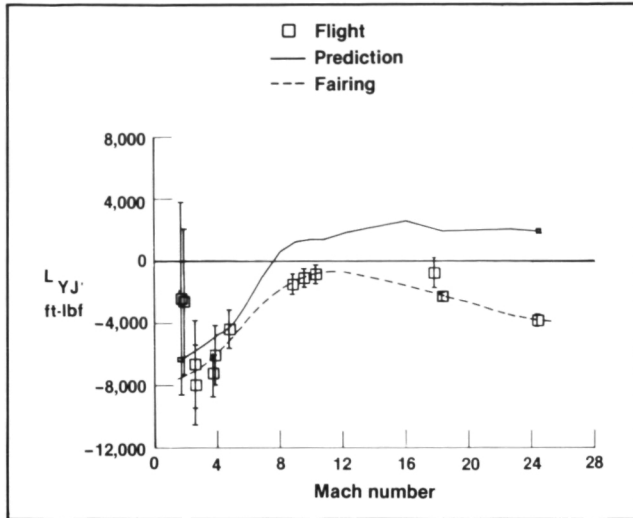
(W. Lokos, Dryden Ext. 3923)



Twist versus load on HiMAT wing

## Parameter Estimation

Parameter estimation is a generic field that involves various disciplines and projects. Much of the parameter estimation work at Ames-Dryden in the past year has been in support of the Shuttle program. Investigations have concentrated on the hypersonic-speed and the low-supersonic-speed flight regimes. Special models for reaction-control jet effectiveness using parameter estimation methods were developed to investigate predicted nonlinearities that were difficult to observe in flight. Significant differences were noted between predicted aerodynamic data and flight-derived data using parameter estimation. The Shuttle flight control system has been modified based on parameter estimation results. Results from the HiMAT flight program also showed differences between predicted data and flight-derived data obtained by parameter estimation. The flight-derived data were used to develop a completely new simulation data base, and to validate the control system used to fly the vehicle at its unstable design point.



*Effectiveness of reaction-control jets on Shuttle Orbiter; induced roll due to yaw jet*

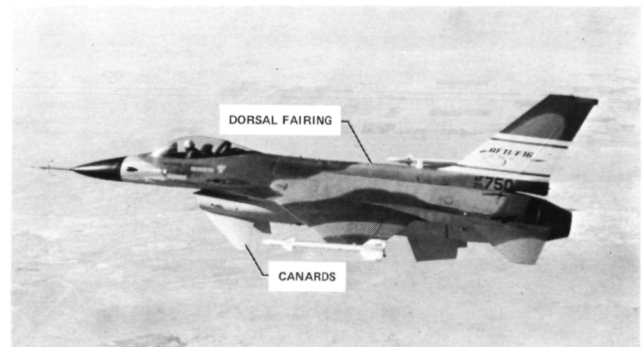
In the high-angle-of-attack regions, parameter estimation research has proved to be a useful tool because the nonlinear modeling problem can now be addressed. Neither linear nor nonlinear aerodynamic models are adequate in this high-angle-of-attack region. Programs have now been developed that are capable of handling indicial function representations described as the aerodynamic responses of an aircraft to arbitrary inputs.

(R. Maine, Ext. 3316)

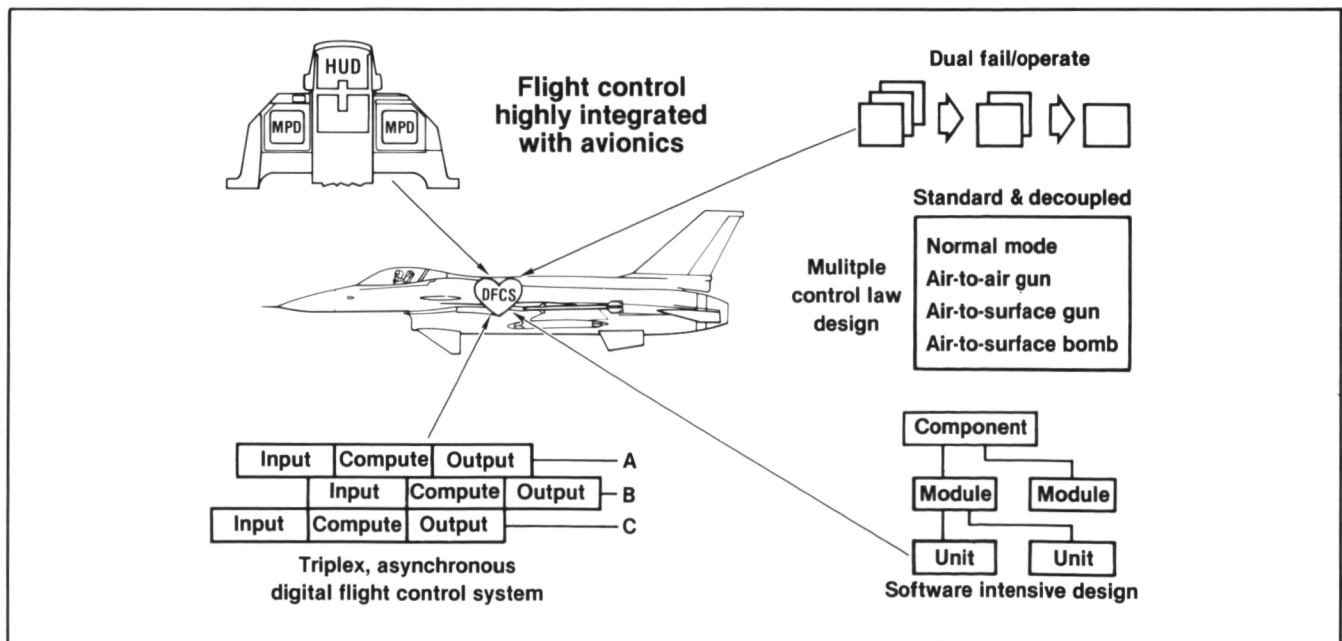
## AFTI/F-16 Flight Test Results

The advanced fighter technology integration (AFTI) F-16 airplane project is a joint Air Force, Navy, Ames-Dryden program that provided the flight test evaluation of a number of new, integrated technologies. Technologies evaluated included a flight-crucial, digital flight control system; multimoded decoupled flight control laws; and integration of advanced cockpit, avionics, weapon, and flight control systems. Flight testing was conducted at the Ames-Dryden Flight Research Facility, where over 115 flights were flown.

The multimoded digital flight control system is the heart of the AFTI system. The heads-up display (HUD) and multipurpose displays (MPDs)



*AFTI/F-16 airplane*



*AFTI/F-16 integrated technologies*

provided a central interface to the pilot for flight control and avionics systems. Mode selection, system configuration, and failure warnings were all available through the MPDs. Retaining the same reliability as a quadriplex analog flight control system at a lower cost was the goal for developing a triplex system capable of operation after two failures. Multimoded, decoupled, flight control laws provide task-tailored aircraft control, which include decoupled motions. Decoupled control options comprise direct lift, vertical translation, and pitch pointing in the longitudinal axis. Direct side force, lateral translation, and yaw pointing are available in the lateral axis. An asynchronous computer architecture and a software-intensive design played major roles in the development and flight test activities.

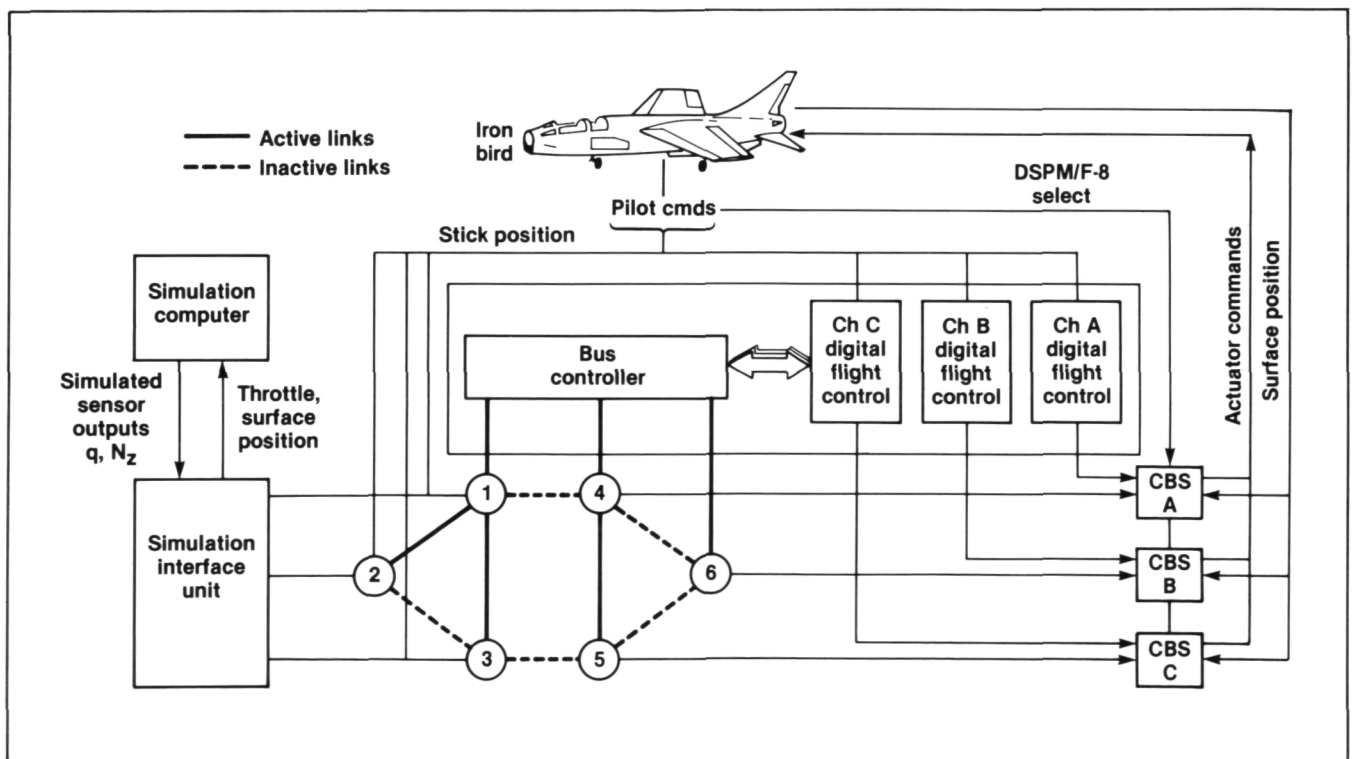
Flight tests centered around the evaluation of the advanced, decoupled flight control laws; the tests indicated that the task-tailored control laws of the AFTI/F-16 provided handling qualities superior in the areas of air-to-air and air-to-ground missions, refueling, and approach and landing when compared with the standard F-16A aircraft. A command-dependent gain system in the pitch axis and a flat-turn capability were judged particularly effective. In addition to the improved effectiveness in its military role, the

AFTI/F-16 airplane provided a generic look at the challenges facing highly integrated flight-crucial control.

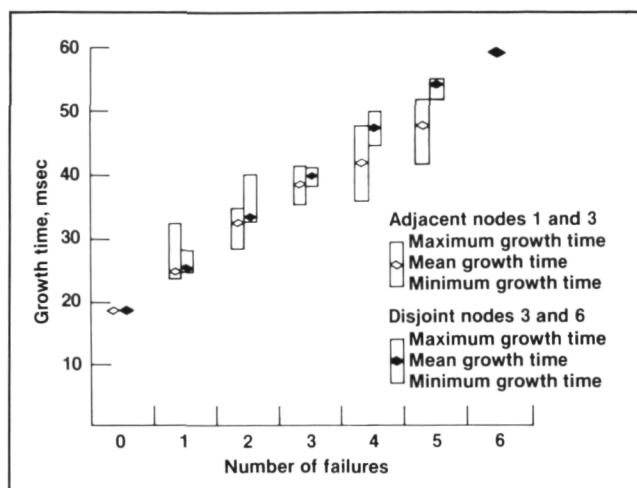
(D. Mackall, Dryden Ext. 3408)

## Dispersed Sensor Processing Mesh Test Results

The dispersed sensor processing mesh (DSPM) is part of an experimental system used to pursue a proof of concept for an advanced fault-tolerant communication strategy. The DSPM experiments incorporate sensors and effectors into an ultra-reliable nodal network in which a central bus controller performs algorithms to grow and maintain the network. The experiments demonstrate that DSPM is an achievable communication network that can sustain failures and continue to function properly. The system consists of three major components: the F-8 DFBW Ironbird simulator, a central computer with simulation software, and a six-node (plus a triplex bus controller) version of



(1) DSPM experimental system



(2) Number of combined failures occurring on two nodes

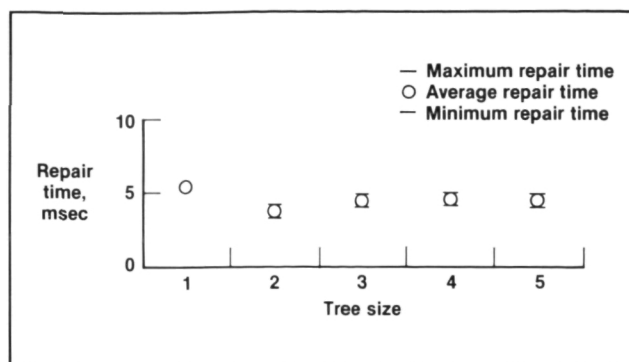
the DSPM network. Preliminary tests on the DSPM system concentrated on four areas. The tests had to: establish DSPM's capability to detect, identify, and isolate faults correctly; establish DSPM's capability to sustain, with no perceptible effect, failures while engaged in flight simulation; measure actual performance of the growth algorithm under varied fault conditions; and measure the performance of the repair algorithm under varied fault conditions.

Preliminary data on the growth algorithm for all failure combinations up to three failures per node for adjacent nodes and disjoint nodes indicate three characteristics of the DSPM growth algorithm: (1) growth time is linearly related to the number of faults; (2) the growth time for disjoint nodes is slightly more than for adjacent nodes; and (3) even though the growth algorithm is deterministic, there is a wide deviation in the growth time given the same number of faults.

Once a network is grown, the DSPM system handles additional failures in two ways. Once a failure is detected the system tries to "repair" itself. If in the repair process another failure is encountered, the repair is aborted and the network is regrown. However, use of the repair routine is preferable. The average repair time of the DSPM network is substantially less than the average growth time for a fault-free network. Further, the repair time for all trees ranging from 1 to 5 nodes was about 4.5 msec.

The DSPM program demonstrated the validity of the basic DSPM concept. The system

1. Successfully detected, identified, and isolated faults. The faults included single and multiple faults to links and nodes.



(3) Number of nodes in tree with fault

2. Operated in a real-time (30-msec) Ironbird simulation of an advanced, digital, fly-by-wire aircraft with no perceptible difference from the standard F-8 system.

3. Reconfigured around faults in real time with no perceptible transients in the flight-control system.

(L. Abbott, Dryden Ext. 3677)

## Aero-Assisted Orbital Transfer Vehicles

Conceptual studies are being performed using vehicles that would (1) extend the utility of the Space Shuttle, and that would (2) make effective use of Earth-lunar space. By performing vehicle maneuvers in the upper layers of the Earth's atmosphere, the payload can potentially be increased threefold, by reducing fuel requirements. Two generic vehicle concepts show particular promise. One is primarily useful for transporting large payloads between two low-Earth orbits, or from low-Earth orbit to distant locations (such as geosynchronous orbit, or a stable libration center at lunar distance). The vehicle maneuvers primarily by drag in the Earth's atmosphere, and achieves orbit-plane inclination change propulsively at its apogee where fuel requirements are minimal.

A second generic vehicle concept is a very high-lift configuration. This high-lift capability is essential if time-constrained maneuvers are to be made with aeroassist for low-Earth orbits. Further investigation is being done for an advanced version of this concept that can descend through the atmosphere and land on the Earth.

Concurrent studies of the effective use of Earth-lunar space by such vehicles involve the subtle interaction of many physical phenomena. Results are nonintuitive; for example, a given vehicle can retrieve three times the payload from a distance of five times geosynchronous orbit as it can from simple geosynchronous orbit.

(J. Howe, Ext. 6113)

## Advanced Heat-Shield Materials

Several flexible and rigid materials, with different advantages over the baseline Space Shuttle heat-shield properties, are undergoing preliminary studies for potential use on advanced space vehicles having increased materials performance requirements. These materials are in varying states of evolution. One such material is a fibrous refractory composite insulation (FRCI-40-20) which has commercial promise, since it is machinable and is a stronger rigid insulation material than any baseline material. This material was successfully produced in the laboratory, tested at high temperatures in a convectively heated environment, and then upgraded to a pilot-plant scale. A second material under development is an advanced flexible thermal protection system (TPS), called Tailorable Advanced Blanket Insulation (TABI). This material utilizes a three-dimensional integrally woven core structure that is design-adjustable, with controlled, multilayered, multi-component cell geometry. One version, a silica yarn construction, silica-filled unicomponent,

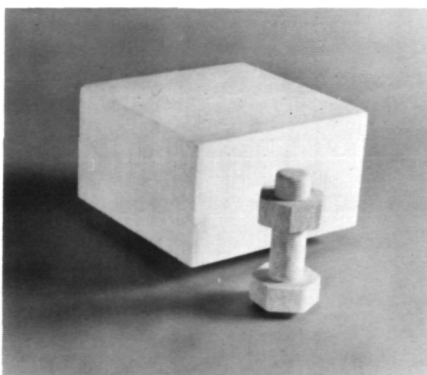
unilayered system, has been put through a preliminary aeroacoustic screening test in a transonic wind tunnel to demonstrate the feasibility of three-dimensional woven structures as an advanced TPS system. Finally, an alumina-enhanced aluminoborosilicate insulation with a higher temperature capability than any baseline material has been successfully fabricated in the laboratory and tested in a convective heating environment to 150°C.

(H. Goldstein, Ext. 6103)

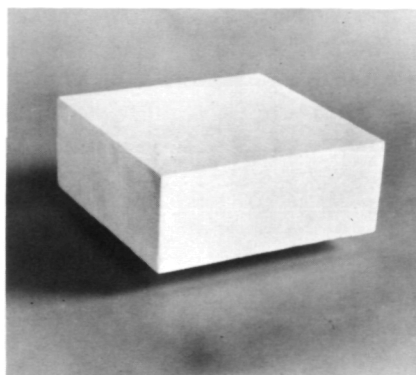
## Shuttle Orbiter Experiments Program

Shuttle operational flights provide an opportunity to evaluate new thermal protection concepts and materials in the actual Earth-entry environment. The Advanced Ceramic Thermal Protection Systems experiment is designed to take advantage of Shuttle flights to evaluate several materials and systems that are products of advanced heat shield materials research programs and which have been screened from ground tests. Several surface areas on the Orbiter having the necessary instrumentation were selected to represent the range of actual aeroacoustic and aerothermal environments encountered during launch and reentry.

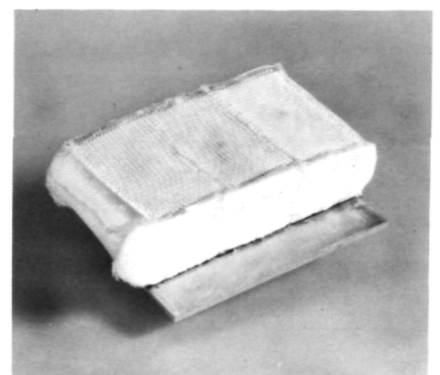
The first two materials systems to be flown are the Tailorable Advanced Blanket Insulation (TABI) and the Direct Bond Composite Panel.



TOUGHER FRCI

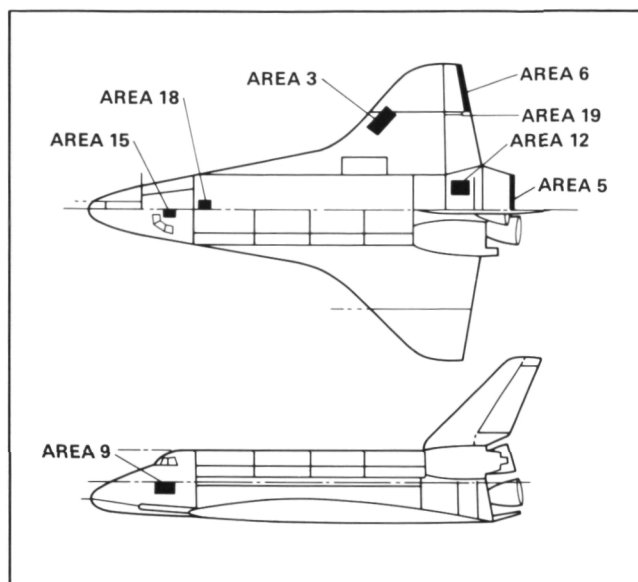


HIGHER TEMPERATURE  
INSULATIONS



TABI

*Advanced materials for future atmospheric entry vehicles*



*Advanced ceramic TPS experiment*

The TABI results from basic research and technology efforts to develop flexible blanket insulations that have potentially superior temperature and mechanical capabilities for a wide range of thermal protection applications. The Direct Bond Panel experiment will obtain flight data on Fibrous Refractory Composite Insulation (FRCI) tiles glued to graphite-polyimide carrier panels that are mechanically attached to the Orbiter structure at appropriate locations. Experimental configurations for both of these materials systems have been designed, and Shuttle flights are planned in 1985.

Results from this experiment are not planned to provide replacement of the current Orbiter heat shield materials, but will reduce the development cost and time, and thus permit faster availability of improved thermal protection systems for advanced space vehicles. In addition, comparison of ground and flight data from these evaluations will improve simulation techniques and requirements in ground-based facilities.

(H. Goldstein, Ext. 6103)

## Space Shuttle Main Engine Flow-Field Simulation

A computer code has been developed which permits simulation of the viscous, incompressible flow field around and inside a variety of practical configurations. This code (INS3D) solves the

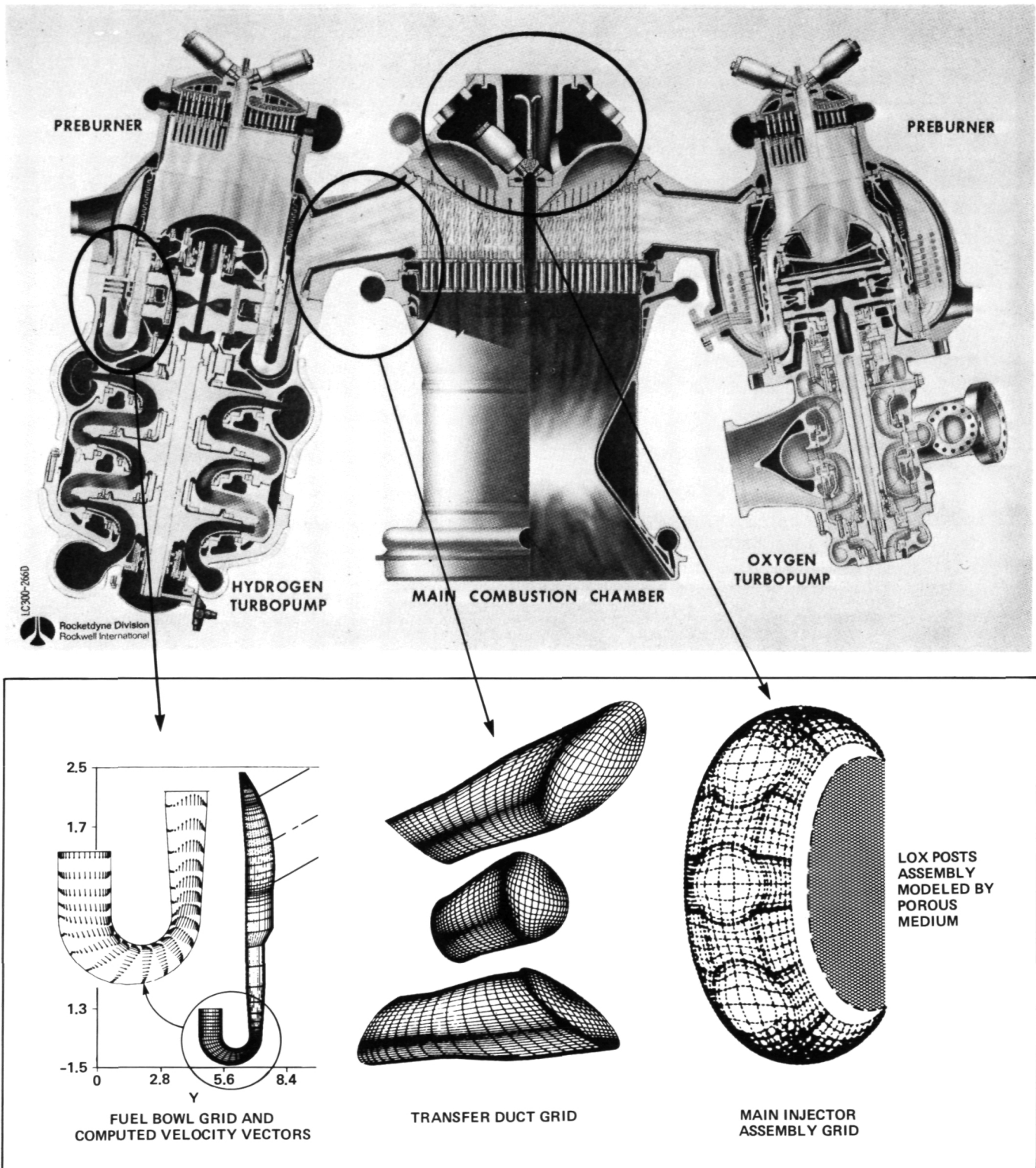
incompressible Navier-Stokes equations in a three-dimensional curvilinear coordinate system. INS3D is currently being used to analyze the flow field in the SSME power head. The overall objective of the SSME power head simulation is to determine flow induced loads on liquid oxygen (LOX) posts, then to quantify the flow field to reduce the loads. In redesigning the power head to increase engine thrust and hence the Shuttle payload, this code will be implemented to verify the performance of new configurations, and thus to refine design and testing procedures.

(P. Kutler, Ext. 6032)

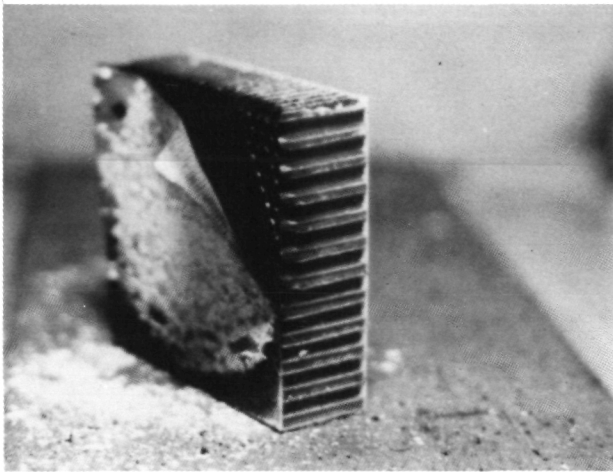
## Lightweight, Fire-Resistant, Aircraft Interior Panels

A lightweight and fire-resistant panel has been developed which consists of graphite fabric face-sheets impregnated with polystyrylpyridine (PSP) resin. This advanced panel provides a weight savings over currently used fiberglass facesheet panels used in aircraft interiors. The development of these panels and other similar panels is done with the support of the Federal Aviation Administration (FAA), and involves commercial companies, such as American Cyanamid (resin development), Hercules, Inc. (prepreg and panel development), Douglas Aircraft, and Lockheed Corporation (decorative film development). This advanced panel, C, has been tested and compared with the baseline epoxy glass panel, A, and a phenolic-glass panel, B. A radiant heat source was used to test the panels, which exposed them to a heat flux of  $5 \text{ W/cm}^2$  to determine the rate of mass loss under this heating condition. Panels A and B show significant damage to the front face of each, whereas panel C was almost completely intact after exposure to the same heating rate. Currently, large panels are being constructed from these resins and from a modified PSP resin which is to be tested under full-scale conditions in the C-133 aircraft at the FAA Technical Center, Atlantic City, N.J. In addition to the fire-resistant properties, panels constructed from these graphite fabrics offer a weight savings of approximately 500 lb in a typical wide-body aircraft and provide fuel savings of up to 2.5 million gallons per year for the typical fleet of 300 wide-body aircraft in the United States.

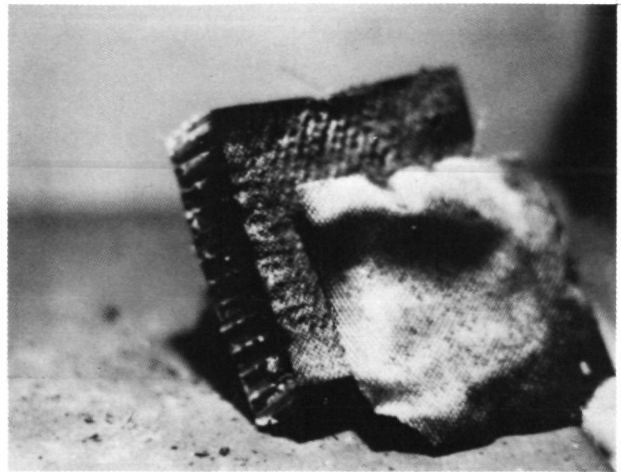
(D. Kourtides, Ext. 5226)



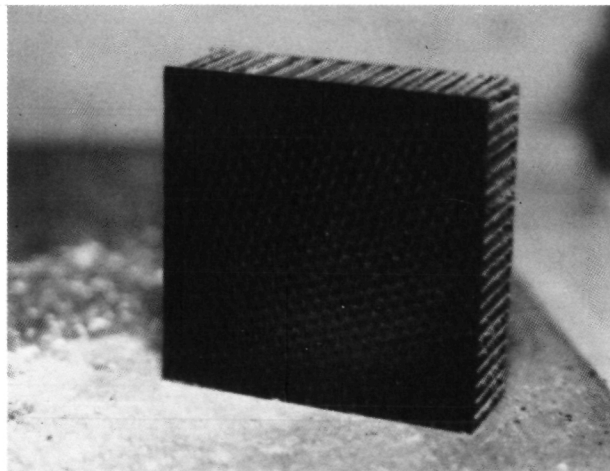
*SSME powerhead component arrangement*



A. Epoxy Glass Fabric Faced Composite Panel (Baseline)



B. Phenolic Glass Fabric Faced Composite Panel



C. PSP Graphite Fabric Faced Composite Panel

*Results caused by pyrolysis at flux level of  $5.0 \text{ W/cm}^2$  for three composite panels*

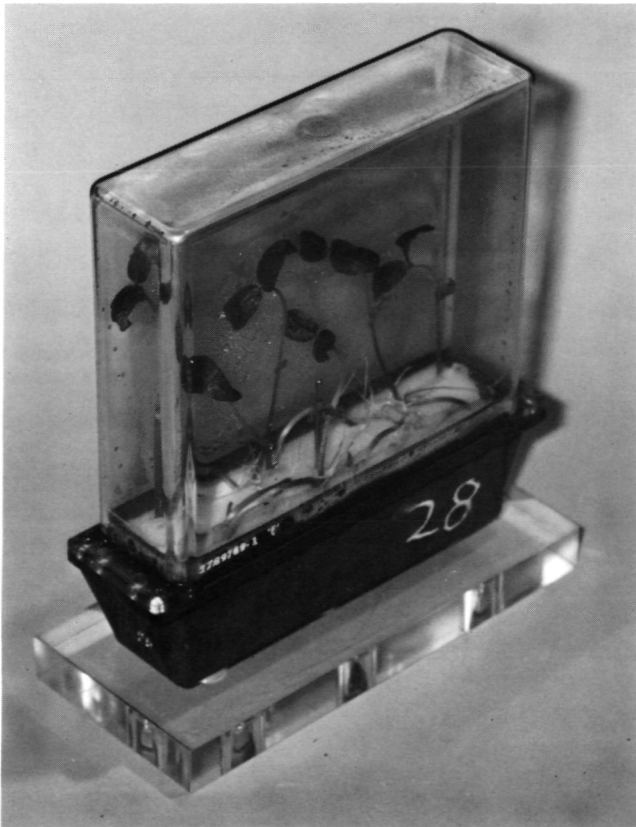
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# Life Science

## Plant Growth Unit

Results of the OSS-1 mission, in which the NASA Ames-developed Plant Growth Unit was used to monitor the growth of plants, were reported by Dr. Joe Cowles of the University of Houston at the International Congress of the AIAA and at the annual meeting of the American Physiological Society. It was found that roots of the bean and oat plants grew in random directions during exposure to weightlessness. Some enzyme activities and protein content differed between flight plants and ground-based control plants. Minor modifications to the Plant Growth Unit for SL-2 and subsequent missions were recommended. These modifications are being implemented, and will provide flight equipment useful for a variety of future plant experiments.

(E. Merek, Ext. 6745)



*Plant growth unit*

## Spacelab 4

Spacelab 4, the first Shuttle mission dedicated to the Life Sciences, is scheduled to fly in late 1985. Ames Research Center is managing 14 principal investigators which include three scientists from NASA, nine from U.S. universities, and one each from Great Britain and Australia. Ten of the NASA Ames sponsored experiments use squirrel monkeys or rats as subjects to complement data which will be obtained from human-based investigations. The other four experiments will test fundamental biological responses to gravity in squirrel monkeys, frogs, and plant seedlings.

The NASA Ames investigations are grouped into eight scientific disciplines: two cardiovascular experiments will measure changes in arterial and central venous blood pressures, aortic blood flow, and various microcirculatory parameters in rats; three experiments on several rat muscles will examine the effects of weightlessness on ultrastructure, energy metabolism, and the functional characteristics of contractile proteins; two experiments using squirrel monkeys as subjects will monitor central fluid shifts, blood hormone fluctuations, urine fluid and electrolyte responses, thermoregulation and circadian rhythms of several physiological parameters; one investigation will measure ultrastructural alterations in rat vestibular organs and another will observe calcium balance and bone formation during and following flight; two investigations will measure erythropoiesis and regulation of blood volume in rats; two investigations will videotape the geotropic and phototropic responses of plant seedlings; and one experiment will follow embryogenesis of frogs from fertilization through maturation.

Ames Research Center and the prime contractor, Management and Technical Services Company, have been developing experiment-unique hardware during the ground-based phase of experiment development.

(C. Schatte, Ext. 6748)

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## Primate Feeder for Space Shuttle Physiology

The Ames Mechanical Systems Branch designed a squirrel monkey feeding system to integrate with the existing Spacelab Research Animal Holding Facility (RAHF). The system was required to deliver one 190-mg pellet to the monkey on demand. Because of crew time constraints, the feeder incorporated a replaceable food cartridge system. A reduced capacity feeder was constructed and tested successfully. A full capacity prototype is presently under construction.

(R. Peyran, Ext. 6316)

## Spacelab IV Primate Urine Collection System

The Ames Mechanical Systems Branch has developed a urine collection system for a male squirrel monkey aboard Spacelab. The system will automatically collect urine at 4-hr intervals and store it for up to 36 hr or longer. The design is a passive garment type apparatus which has been proven to be biocompatible and nongravity sensitive. Flight-qualified units are now being fabricated.

(P. Fusco, Ext. 5229)

## Spacelab IV Embryology Experiment Hardware

The hardware to support the Spacelab IV Embryology Experiment has been developed by the Ames Mechanical Systems Branch. This experiment is designed to test the effect of weightlessness on the fertilization and early development of frogs' eggs. The hardware design includes: a 1-g centrifuge, a device to inject fixation (i.e., preserve the embryos at various stages of development), a temperature-controlled environment, a method to transport live frogs, storage, electronics, and support equipment. Problems encountered have been: fluid behavior

in zero-gravity, safety, and biocompatibility. The space flight hardware is now in fabrication.

(R. Mancini and R. Johnson, Ext. 6319/6315)

## Fetal Development During Spaceflight

Studies are under way of visual, vestibular, and olfactory receptors and associated nervous pathways in fetal and postnatal rats that have undergone fetal development during spaceflight. Hardware designed to evaluate subtle behavioral or functional changes during *in-utero* exposure to zero gravity has been developed. The equipment allows examination of the onset and levels of neuro-sensory function using behavioral response indicators. The equipment also allows assessment of maternal behavior of the dams after giving birth to determine effects of spaceflight exposure on maternal interactions with offspring.

(E. Gomersall, Ext. 5730)

## Activity and Temperature Rhythms in Space

Means to monitor the external and internal synchronization of the circadian time-keeping system in space have been developed. Flight subjects are conditioned to wear sensors for the duration of the flight so that activity and skin temperature variations can be monitored. Activity is obtained from a piezoelectric film sensor that can be attached directly to the subject (e.g., as a bracelet, or to leads from other sensors). Activity is recorded as the sum of events above a preselected threshold during a preselected time interval. Skin temperature is obtained from a thermistor glued directly to the subject. Temperature is recorded at preselected intervals. A compact, solid-state flight recorder has been developed by adapting commercial recorders into a battery-powered flight-hardened configuration. Ground-based experimental results using non-human primates have shown the system to monitor successfully subjects for up to 2 weeks duration.

(E. Gomersall, Ext. 5730)

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## Biological Adaptation to Weightlessness

The stable range of normal bodily processes will undergo a modification with a change of environment, such as a change in temperature, pressure, or gravity. Eventually, the body achieves a new steady state, according to the demands of the new environment. In the weightlessness of space, when the body requires less structural support against the force of gravity, changes occur in portions of the musculo-skeletal system. The normal rates of tissue formation and degradation change as the body adapts to weightlessness in space (or inactivity on Earth). These adaptive changes result in a net loss of mass and strength in muscle and bone. NASA Ames scientists are conducting studies of the biological reasons behind such changes in organisms during weightlessness.

Spaceflight experiments have systematically demonstrated that load-bearing, or gravity-dependent muscles and bones atrophy in rats during spaceflights. In addition to suppressed bone growth and loss of bone mass, when the period of weightlessness is about 3 weeks, bone may completely stop forming and become weaker than the bones of Earthbound animals. Following recovery of the animals on Earth, their bones returned to normal after about a month, with the exception of loss in the connective fibers, the trabeculae. Losses in skeletal muscle, particularly in the soleus, or calf muscle, were also noted. Strength in the femur, or thigh bone, was maintained during flight by increasing gravitational forces on the rat in a centrifuge on-board an unmanned satellite.

Improvements were made in a method to simulate the effects of weightlessness in rats on Earth. Rats kept in the environment of a simulator called the PULEH (Partially Unloaded by Elevating the Hindquarters) showed comparable results to rats that were flown in space. After 6 days the soleus lost 30% of its muscle mass. In addition, energy synthesis was 67% lower in the mitochondria taken from the cells of atrophied muscles. Because high levels of certain steroids were known to cause severe lesions in muscle mitochondria, these glucocorticoids were also measured. Glucocorticoids accelerated

muscle atrophy during simulations on Earth. While glucocorticoids may be actively involved in muscle atrophy, the precise process remains unknown.

(E. Holton, Ext. 5471)

## Cardiovascular Response in Humans During Repeated Simulations of Space Shuttle Flight

Over the past decade, the NASA Ames Human Research Facility has pioneered the use of bed rest in a head-down position of  $-6^\circ$  as an accurate simulation of certain effects of weightlessness on the human body. Experiments have been conducted with over 180 subjects, including participants in the first female bed-rest study. Testing subjects' cardiovascular reactions on the Human Centrifuge following bed rest has allowed researchers an opportunity to identify physiological characteristics of individuals who may experience a serious loss of blood pressure during reentry acceleration. The Space Shuttle is unique among manned spacecraft because the human body is subjected to accelerative forces in the  $+z$  axis, from head to foot. Athletes with an expended cardiovascular capacity and requirement due to conditioning by aerobic exercise, such as running and bicycling, were found to be more susceptible than sedentary subjects to loss of blood pressure during exposure to a simulated Shuttle acceleration stress of  $+3g$ .

As part of a 3-yr study, NASA researchers, funded under the Operational Medicine and Biomedical Research programs, collaborated with Stanford University and the Kaiser Foundation Research Institute to determine: (1) the extent of cardiovascular deconditioning; (2) the rate of recovery following repeated bed-rest periods of 10 days each, mimicking the duration of Shuttle flights; (3) quantitative measures for individuals who face the greatest personal risk in space, to support the selection of an ever-growing number of nonastronaut payload specialists; and (4) possible countermeasures among a variety of promising cardiovascular medications. Among the

blocking agent which suppresses the sympathetic nervous system serving the heart and artery drugs tested were those that help to constrict blood vessels and elevate blood pressure, such as phenylephrine and propranolol, a beta-adrenergic walls. Also tested was atropine, an anticholinergic (a substance that inhibits parasympathetic nerve action) used to suppress normal function of the vagus nerve to the heart.

These drugs may help the body maintain normal blood pressure during exposure to orthostatic stress. They are commonly used in medical practice with a wide margin of safety when properly prescribed.

(D. Goldwater, Ext. 5749)

## Control of Aerospace Sickness by Biofeedback-Assisted Training

Psychophysiology, the study that applies the findings of neurology to behavioral research, was used by the NASA Ames Biomedical Research program to enhance astronaut performance by alleviating the symptoms of motion sickness. The autogenic, or self-induced, training technique has been developed over the past decade at Ames into a reliable system for astronauts and pilots to train themselves to control all symptoms of motion sickness. With this technique of Autogenic Feedback Training (AFT), subjects use biofeedback machines to monitor in real time the selected vital signs of their bodies that are related to motion sickness. U.S. Air Force pilots, who suffered from motion sickness during flight, were able to return to flight duty after learning to control their symptoms using similar biofeedback training.

The USAF requested assistance from Ames to devise a countermeasure to the performance distress of motion sickness for their astronauts, or Manned Spaceflight Engineers (MSEs). MSE candidates were also tested at Ames to obtain baseline physiological measurements under various motion environments on the Lear Jet during parabolic flight profiles that simulated weightlessness for a few seconds, in the VARD flight simulator during vertical acceleration, on a



*Undergarments designed for various body types will allow astronauts to monitor their vital signs during flight experiments, testing self-control of space sickness following biofeedback training on Earth*

rotating chair, and surrounded by a rotating optokinetic drum for a test under visual stimuli.

In collaboration with the University of California's Langley Porter Neuropsychiatric Institute and the Rockefeller University of New York, pioneering centers in biofeedback research, NASA scientists continued the evaluation of new biomedical instrumentation to monitor physiological functions related to motion sickness malaise, such as respiration and heart rate, skin temperature, and movement in the muscles of the digestive organs. The sensors for these monitoring systems, such as those built into specially designed undergarments for ambulatory use, were designed to be noninvasive to the body and unobtrusive to the wearer. Such equipment was tested for eventual use on the Spacelab 3 mission during an experiment, the first in a series of controlled scientific tests to validate the efficacy of AFT in space.

(P. Cowings, Ext. 5724)

## Anti-G Suit for Astronaut Protection and Biomedical Research

Pilots have used an inflatable aviator's suit, or anti-*g* suit, since the 1940s to reduce greyout and blackout during exposure to head to foot accelerative forces. The suit is also carried as a precaution on board the Space Shuttle for use in maintaining adequate blood pressure to the head during reentry.

In the NASA Ames Biomedical Research program, Ames investigators collaborated with researchers from the European Space Agency, Letterman Army Medical Center, and Ullevaal Hospital on anti-*g* suit research. They used the suit to produce lower-body positive pressure (LBPP) to examine the process of headward fluid shifts, similar to those that occur during spaceflight. In studies at the NASA Ames Laboratory for Human Environmental Physiology Research, subjects stood for 3 hr wearing anti-*g* suits. The suit remained deflated for the first hour as a control period, was inflated to 60 mm Hg, providing LBPP for the second hour, and then deflated for a third hour of recovery monitoring. LBPP caused an immediate and sustained 15% elevation of mean arterial blood pressure and a 15% reduction in heart rate. Upon release of suit pressure, heart rate immediately increased 22% to maintain the body's blood pressure.

Radioimmunoassays were used to analyze hormonal activity in blood plasma of subjects. Changes in plasma vasopressin, secreted from the posterior lobe of the pituitary, increased reabsorption of water by the kidney, which helped to maintain the body's blood pressure during the control period, and again in the first 5 min following deflation of the suit. Plasma renin activity (PRA) also increased significantly in the standing subjects during the control and recovery periods. PRA stimulated production of the



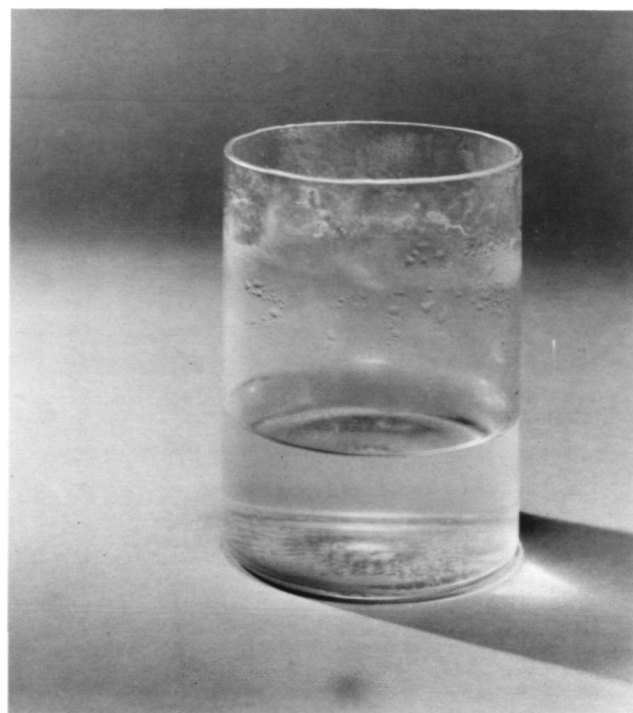
*Subject wearing anti-*g* suit during a controlled study of fluid shifts and hormone changes*

hormone aldosterone, which maintains fluid pressure in the body through retention of sodium by the kidney.

LBPP may be an inexpensive alternative to bed rest and water immersion for the study of some aspects of fluid and electrolyte shifts caused by weightlessness. Definitive measurements of fluid shifts during spaceflight are still required before choosing the most appropriate simulation for use on Earth to study cardiovascular responses to spaceflight deconditioning.

(J. Greenleaf, Ext. 6604)

## Catalytic Wet Oxidation of Spacecraft Waste



*Effectiveness of wet oxidation as a waste treatment process, shown by a plant before (left) and after (right) wet oxidation*

Storing human metabolic products and other wastes in a manned spacecraft over long periods of time is undesirable. Therefore, waste-processing methods are being studied which can reduce the weight and volume of stored wastes. Ideally, the waste processor should also yield nontoxic or nonhazardous products which can be used in the spacecraft environment. One of the methods under investigation at NASA Ames is wet oxidation. Its major advantage is that the waste feed can be oxidized without an energy-intensive predrying step.

During catalytic wet oxidation of a spacecraft model waste which included human urine and feces, a ruthenium on alumina catalyst increased the rate of oxidation of the waste feed and accelerated the conversion of organic nitrogen in the waste feed to nitrogen gas. Nitrogen gas is a desirable product of waste treatment because it can be used to replenish the nitrogen component of the spacecraft atmosphere which is lost through leakage.

(T. Wydeven and C. Johnson, Ext. 5738/5768)

## Carbon Isotopic Fractionation in Microorganisms

The organic matter that is deposited in aquatic sediments is a valuable storehouse of information about the evolution of the biosphere. This information consists of molecular structures, abundances, and isotopic compositions. Certain organic molecules, termed biomarkers, are particularly useful because their structures are unquestionably biological in origin. Because the stable isotopic compositions of biomarkers are established during their biosynthesis, isotopes constitute a useful approach for interpreting sedimentary organic matter.

Fermentative microorganisms play a major role in modifying sedimentary organic matter; therefore, it is necessary to understand how the relative abundances of the isotopes  $^{13}\text{C}$  and  $^{12}\text{C}$  are changed during fermentation. One such organism, *E. coli*, was chosen for the initial

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experiments. When grown aerobically on glucose, *E. coli* respire carbon dioxide which is  $^{13}\text{C}$ -depleted, relative to the glucose, but it excretes  $^{13}\text{C}$ -enriched acetate. In general, those biomolecules whose synthesis requires many metabolic steps are more depleted in  $^{13}\text{C}$  than are molecules requiring few steps. *E. coli* grown without oxygen excretes a variety of low-molecular-weight acids which are relatively  $^{13}\text{C}$ -depleted.

Variations in the  $^{13}\text{C}$  content of microbial metabolic products indeed display systematic behavior which, given the appropriate study of sedimentary microorganisms, will eventually offer a broader insight into the origin of sedimentary organic matter and consequently the evolution of the biosphere.

(D. Des Marais, Ext. 6110)

## **Gas Chromatographic Separation of Atmospheric Gases Using a Custom-Made Porous Polymer**

For planetary entry probes in solar system exploration, atmospheric composition is an important analysis, and gas chromatography is a technique well suited to carry it out. The gases to be analyzed, however, are not always simple to separate since, in many cases, the atmosphere contains nitrogen, oxygen, argon, and carbon monoxide. The analysis of these gases has been a problem for many years. Most analysts must use two-column switching combinations and, in some cases, low, subambient temperature programming, both of which are far too complicated for flight use.

Gas chromatographic column materials which have been used in the past were surveyed, and many of the existing commercial porous polymers were found to have the ability to resolve some of the gases of interest. The more successful polymers contained significant amounts of divinylbenzene (DVB) and ethylvinylbenzene (EVB).

However, the batch-to-batch variation among these commercial polymers was found to be wide, and the performance was unpredictable. To alleviate these difficulties, a study was conducted on porous polymers synthesized in the lab, allowing definition of some of the parameters which affect the properties of the final products. It was found that a high-purity DVB monomer which contained only a small amount of EVB produced a product which would, at ambient temperatures, resolve nitrogen, oxygen, argon, and carbon monoxide on a single column in a predictable and consistent manner.

(G. Pollock, Ext. 6165)

## **Gas Chromatograph for Monitoring Astronaut Denitrogenation Prior to Extravehicular Activity**

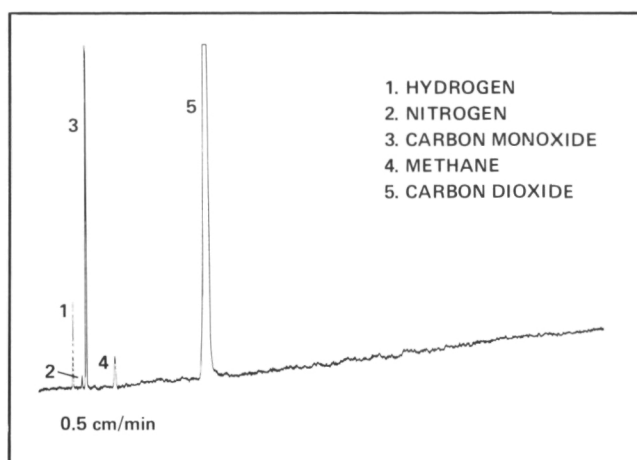
During Shuttle operations, the need to conduct extravehicular activities (EVA) will commonly occur. Since the Shuttle atmosphere is air at sea-level pressure and the spacesuit environment is oxygen at 4 psi, there is a potential for physical complications. An astronaut must prebreathe pure oxygen at the higher pressure for an extended period of time in order to "wash" nitrogen from the body, thus avoiding the bends. There is some indication that this "washing" process proceeds differently in zero gravity. Therefore, a need exists to monitor nitrogen "washing" progress while in orbit.

A laboratory prototype flight gas chromatograph has been developed that is capable of monitoring oxygen and nitrogen in the breath to better than 1% accuracy during the course of oxygen prebreathing. The instrument is made possible by using miniature columns, detectors, and systems developed at NASA Ames for use in future solar system exploration. Further development and engineering activities are being conducted in order to provide an instrument for use on board the Shuttle.

(G. Carle and F. Woeller, Ext. 5765/5769)

## Gas Chromatographic Analysis of Volatiles from Model Comet Dust

Comets are primitive solar system bodies that contain information about the early history of the biogenic elements. This information may be found in the volatile and nonvolatile molecules associated with comet dust. Collecting comet dust and subsequently measuring the associated volatiles will help provide an understanding of the early history of the biogenic elements.



*Gases evolved on heating a 23  $\mu$ g sample of Murray meteorite at 750°C*

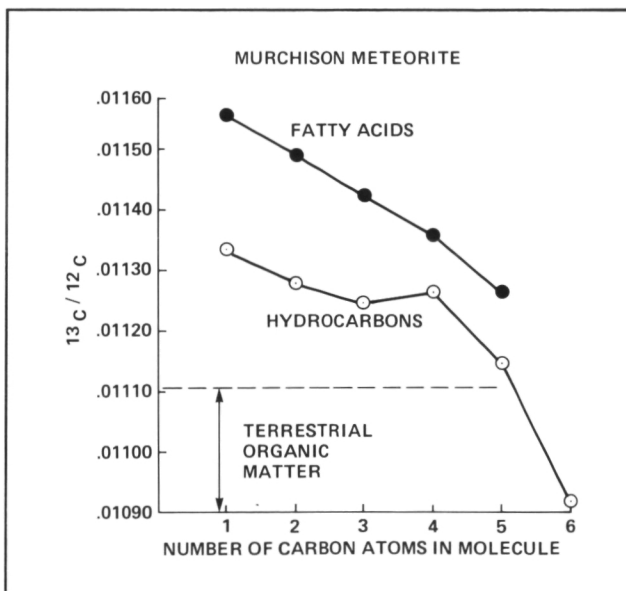
A laboratory prototype of a flight gas chromatographic system has been constructed to measure the volatiles associated with very small quantities of extraterrestrial dust. Nanogram to microgram quantities of carbonaceous meteorites, serving as models of cometary dust, are heated to pyrolysis temperatures. The thermally released volatiles are separated on a selected gas chromatographic column and measured with a metastable ionization detector. Based on experiments with the model dust, it is estimated that nanogram quantities of cometary dust would allow measurement of adsorbed, chemically bound, and entrapped volatiles at the ppm level.

(B. O'Hara, Ext. 5770)

## Carbon Isotopic Measurements as a Clue to the Origin of Meteoritic Organic Matter

The demonstration that organic matter is synthesized in the absence of life is an important step toward understanding prebiotic chemical evolution. Organic compounds had been first identified in meteorites decades ago, but only more recently have investigators demonstrated that at least some of these compounds are not contamination, but are extraterrestrial in origin. Remarkably few attempts have been made to elucidate the mechanisms whereby meteoritic organic matter is synthesized.

This year at NASA Ames, the relative abundances of the two stable carbon isotopes have been measured in several individual hydrocarbons and fatty acids which were isolated from the Murchison carbonaceous chondrite meteorite.



*$^{13}\text{C}/^{12}\text{C}$  values of individual-saturated normal hydrocarbons ( $\circ$ ) and fatty acids ( $\bullet$ ) from the Murchison meteorite versus the number of carbon atoms in the molecules*

The measurements reveal that these compounds are markedly enriched in  $^{13}\text{C}$ , the heavier isotope, relative to organic matter on Earth. This observation confirms that these compounds share an extraterrestrial origin. Second, the larger hydrocarbon and fatty acid molecules are

successively more depleted in  $^{13}\text{C}$ , relative to their smaller counterparts, demonstrating that the larger molecules were synthesized from smaller ones and that the hydrocarbons and fatty acids share a common origin. Future stable isotopic measurements will reveal further details about the fascinating history of meteoritic organic matter. These details will tell us more about the organic chemistry which accompanied the birth of our solar system.

(D. Des Marais, Ext. 6110)

## Quantum Chemical Modeling of Reactions on Interstellar Grains

One epoch in the cosmic history of the elements and compounds that make up life takes place in clouds of interstellar gases and grains. Despite the variety of organic molecules that have been observed in the interstellar medium, the contributions made by processes occurring on the grains are poorly understood. Laboratory simulations of such processes are usually impractical, but modeling the reactions with theoretical quantum chemical calculations could yield insight into the roles that grains play in interstellar chemistry. The usefulness of this approach has been limited in the past by its inability to deal with the large number of atoms that is required to model a grain. A modified, iterative extended Hückel program has now been developed which can accommodate upwards of 50 atoms, thus bringing quantum chemical calculations of grain processes within reach.

The modified program was used to study the adsorption and recombination of hydrogen atoms on a model graphite grain. This test system was chosen for its relative simplicity, the availability of both theoretical and experimental work for comparison, and its putative involvement in the formation of hydrogen gas ( $\text{H}_2$ ) and simple hydrocarbons in interstellar clouds. The calculations revealed a large energy barrier against the formation of  $\text{H}_2$  on a graphite surface. Although hydrogen atoms can adsorb on the graphite grain, the probability that an encounter between them will lead to  $\text{H}_2$  formation is no greater than 1/2,000, much less than is required to produce the apparent abundances of  $\text{H}_2$  in the dense interstellar clouds. The results indicate that

other kinds of grains, including nongraphitic carbonaceous grains, merit more consideration. When applied to other more complex reactions, the quantum chemical approach can yield chemical insights that complement those available from either laboratory experiments or strictly physical models of interstellar grains.

(S. Chang, Ext. 6206)

## Photochemical Reactions of Carbon Monoxide and Water in the Primitive Atmosphere of Earth

Uncertainties about how Earth acquired its atmosphere permit a wide range of possible atmospheric compositions for the prebiotic Earth. These possibilities range from a highly chemically reducing atmosphere containing water, methane, ammonia, and abundant hydrogen to a chemically nonreducing atmosphere containing water, carbon dioxide, and nitrogen (the main constituents observed today minus oxygen and ozone). Although it has been shown that the synthesis of organic compounds necessary in the origin of life can be readily achieved in the reducing atmospheres, other atmospheric compositions have received little attention.

For this reason an intermediate case was selected for study, one containing water, nitrogen, carbon monoxide, and carbon dioxide, which is consistent with the entire geological record back to 3.8 billion years ago. As a result of irradiating these gases with ultraviolet light, in simulations of the effect of sunlight on the prebiotic atmosphere, a variety of organic compounds is formed in moderate yield, including acids, alcohols, aldehydes, ketones, and hydrocarbons. Moreover, little if any molecular oxygen is formed concomitantly, which suggests that as long as carbon monoxide or another chemically reducing gas was a component of the volcanic constituents released into the atmosphere, oxygen would not have arisen in the absence of living organisms. However, these experiments also showed that photochemical processes cannot incorporate the element nitrogen from nitrogen gas into organic matter.

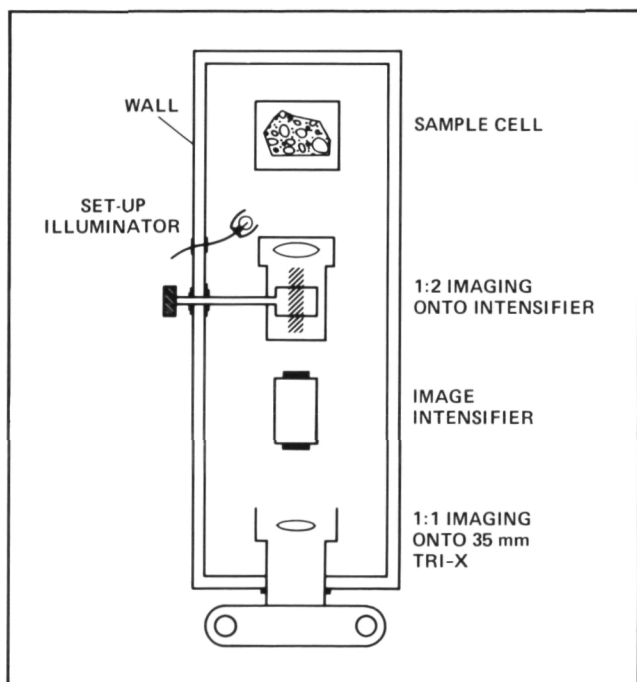
Apparently, in an atmosphere much like that of the present day but without oxygen and its

oxidizing properties, primary prebiotic organic compounds would have been synthesized naturally. According to model calculations based on the experimental yields of compounds, the prebiotic oceans could have been  $10^{-4}$  to  $10^{-2}$  molar in organic compounds from the earliest times. Whether these amounts were enough to allow chemical evolution to proceed, how organic chemical forms of nitrogen became available, and how the organic matter could have been transformed in the surface environments of the prebiotic Earth to living systems, are questions that remain to be answered.

(S. Chang, Ext. 6206)

## Luminescence Imaging: A Novel Approach to Surface Studies

Many minerals and organic materials emit visible light upon exposure to aqueous solutions and organic solvents. The observed magnitude of these luminescence phenomena suggested that, by using light intensifiers, an imaging system could be constructed to form two-dimensional



*Schematic of a prototype luminescence microscope*

pictures of the distribution of light-emitting areas on the surface of a sample undergoing chemical reactions. To this end, a simple luminescence imaging chamber was constructed. Light emitted by the sample under study was imaged by an f/1.4 camera lens onto the front surface of a microchannel plate intensifier. The intensified image was viewed by a 35-mm reflex camera. A rack and pinion focusing assembly with baffled shaft extension was used to bring the front lens into focus. A small lamp, operated at extremely low light level, illuminated the sample during focusing and alignment.

With this apparatus it was possible to photograph the luminescence of an organic compound, luminol, catalyzed on the surface of a montmorillonite clay and that of sea sand exposed to hydrofluoric acid solution. The hydrofluoric acid-sand reaction had not previously been recognized as a chemiluminescent phenomenon. Nevertheless, like many other reactions, it produces chemiluminescence at a level that can be detected and imaged with efficient optical systems and state-of-the-art quantum light detectors. These observations made in the prototype chamber demonstrate that luminescence imaging (a convenient term might be "luminography") of surface reactions at low light levels is clearly feasible.

(S. Chang, Ext. 6206)

## SETI — The Search for Extraterrestrial Intelligence

In FY 83, NASA established SETI as a part of its Exobiology program, whose goal is to understand the origin, evolution, and distribution of life in the Universe. The objective of the SETI research and development program is to determine the most cost-effective way to search the microwave region of the spectrum for radio signals of extraterrestrial intelligence, using existing radio-telescope facilities and SETI-specific ancillary analysis equipment.

Major Ames SETI activities during FY 83, involving collaboration with San Francisco State University, Stanford University, and the University of California at Berkeley, include: (1) continued development of the prototype spectrum analyzer and related SETI instrumentation

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being built at Stanford (current plans call for the equipment to be in the field for tests in FY 84); (2) development of software for a data-acquisition system to control and monitor the SETI instrumentation; (3) development of signal identification algorithm software for the SETI VAX 11/750 computer; and (4) continued pre-

liminary SETI observations at various observatories, such as Arecibo, Puerto Rico and Nancay, France, and reduction of the data using the Ames central computer facilities.

(J. Wolfe, Ext. 5518)

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# Space Science and Applications

## Cryogenic Mirror Test Facility

One of the critical problem areas of technology for spaceborne telescopes is the development of suitable lightweight mirror materials and designs for satisfactory performance at extremely low temperatures. This is particularly true for applications in infrared astronomy where the optical elements may be cooled to temperatures as low as  $-265^{\circ}\text{C}$ . The successful solution of this problem requires a sophisticated test apparatus in which the optical and thermal properties of the mirrors may be accurately measured. The Cryogenic Mirror Test Facility was developed to meet these needs. It consists of: (1) a large dewar for holding the cryogenic coolant — in this case liquid helium — and insulating the optics from the laboratory; (2) mechanical isolation of the dewar to eliminate the effects of spurious vibration in the optical measurement; and (3) sophisticated, laser-based instrumentation for evaluating the optical parameters of the mirrors. The distortion of the mirror surface resulting from thermal stresses or cooling can be measured to within a small fraction of the wavelength of the light for which the mirror is designed. Mirrors have been tested at temperatures as low as  $-265^{\circ}\text{C}$  and there are plans to go to lower temperatures in the future.

(F. Witteborn, Ext. 5520)

## Study of the Radiative Effects of the Arctic Haze

The Arctic, which lies far from most major sources of pollution, has been traditionally considered a remote region where the air and water are still clean and pure. However, during the last 25 yr, each winter-early spring season has seen a remarkable increase in the concentration of man-made pollutant particles (haze) in the Arctic atmosphere. An important component of

the Arctic haze is black carbon, which is a very efficient absorber of solar radiation. The solar energy absorbed is converted into heat and results in an increase in the temperature of the atmosphere. A consequence of this temperature increase is the alteration of the local climate with potential for global climatic changes that may be forthcoming as the result of a steady buildup of light-absorbing haze over the northern polar cap of the Arctic. These effects are enhanced during the early spring, when both the carbon concentration is high and the Sun elevation is sufficient for a considerable amount of solar radiation to reach the Arctic.

In order to determine for the first time the magnitude of the radiative effects of the Arctic haze, we flew repeatedly over the Arctic during March-April 1983. We found the haze to be much denser and more extensive than expected (comparable to urban areas in its black carbon content). The analysis of our experiments shows that the heating of the atmosphere by the Arctic haze-absorbed sunlight is 2 to 3 times larger than normal. There is no doubt that heating of this magnitude can modify the local climate, but the exact effects of these perturbations in the Arctic energy budget are difficult to assess because of the complicated interaction with ice physics and atmospheric dynamics. However, we can speculate that the increased absorption of solar radiation will enhance the melting rate of the pack ice, but without further investigation this remains open to question.

(F. Valero, Ext. 5510)

## Climatic Effects of Volcanic Particles

The massive El Chichon volcanic cloud is being intensively studied from a variety of airborne platforms managed by NASA's Climate Program Office. Subsequent to the detection of sulfur gases and ash particles in the stratosphere from the Mexican volcano in early April, the cloud's physical, chemical, and radiative properties have been sampled *in situ* by experiments carried by a NASA U-2 aircraft, vertically probed by experiments on a University of Wyoming balloon, and remotely sensed by experiments flown on

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NASA's Convair 990 aircraft. Scientists from a number of universities, NASA centers, and other government agencies and research centers are in charge of these experiments. The data collected from these various airborne platforms, in conjunction with data obtained from the ground and from such satellites as SME, will provide a comprehensive data set for evaluating the effects of the El Chichon cloud on temperature and wind patterns in the stratosphere and troposphere. The El Chichon cloud consists primarily of submicron-sized sulfuric-acid particles and micron-sized ash particles that are coated with sulfuric acid. A small amount of salt (sodium chloride) particles is also present. In the northern tropics, the cloud had an optical depth of about 0.25 from April through Aug. 1982. By Dec. 1982, the cloud had spread throughout most of the northern hemisphere and had an optical depth of 0.1. Preliminary radiative modeling of these results shows that during its first 6 mo, the cloud caused the albedo of the northern tropics to increase about 10%, the amount of sunlight reaching the ground to decrease by about 2-3%, and the temperature in the stratosphere at 30 mbar to increase by about 3 K. Chemical-aerosol models are able to reproduce many of the observed cloud properties, including particle size, vertical and horizontal distribution, optical depth, and lidar backscatter cross section.

(J. Pollack, Ext. 5530)

## Atmospheric Evolution Studies

Theoretical models are being used to study various aspects of atmospheric evolution on Earth and Venus. The discovery of an enhanced deuterium to hydrogen ratio in the Venus clouds indicates that Venus was originally endowed with much more water than is now present. The most probable loss mechanism for this water is photodissociation of H<sub>2</sub>O molecules in the upper atmosphere, followed by escape of hydrogen to space and reaction of oxygen with reduced minerals in the crust. Models predict that Venus could have lost the bulk of a terrestrial ocean in this fashion in less than a billion years. An interesting question, which has not yet been answered

satisfactorily, is under what conditions could a similar catastrophe happen on the Earth?

Studies of terrestrial atmospheric evolution have focused on the factors controlling the climate and atmospheric oxidation state on the early Earth. Models of stellar evolution predict that the early Sun was 25-30% less luminous than it is currently. Unless the atmospheric greenhouse effect was larger than today, the Earth's mean surface temperature would have been below the freezing point of seawater prior to 2 billion years ago. Since geological evidence indicates that liquid water was present as early as 3.8 billion years ago, it may be that the atmospheric greenhouse was bolstered by greatly enhanced carbon dioxide concentrations. It has now been shown that up to 1000 times the present level of 300 ppm of CO<sub>2</sub> is required to keep the mean surface temperature above freezing. Such large CO<sub>2</sub> concentrations would have affected the atmospheric oxidation and surface chemistry. An understanding of the past evolution of the Earth's atmosphere is an important aspect of NASA's solar system and global habitability programs.

(J. Kasting, Ext. 5233)

## Studies of the Atmosphere and Ionosphere of Venus

It has been shown that the middle cloud layer of the atmosphere of Venus probably contains wave-like disturbances similar to those known to be important in the Earth's atmosphere. These "baroclinic waves" may explain several wave features seen in the upper Venus atmosphere by the Pioneer Venus Orbiter. An improved understanding of the atmospheres of both Venus and the Earth will result from this sister-planet comparison. Also, a group at Ames and at the University of Santa Clara has developed a two-dimensional dynamical model of the ionosphere of Venus. Preliminary velocity predictions from the model are in excellent agreement with the horizontal plasma velocities observed by the retarding potential analyzer experiment on board the Pioneer Venus Orbiter.

(R. Young and R. Whitten, Ext. 5515/5498)

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## Planetary Satellite Studies

Ames researchers are studying a variety of problems associated with planetary satellites, concentrating on the moons of Jupiter and Saturn first viewed in detail by the Voyager spacecraft. Theoretical work led to the prediction of intense volcanic activity on Jupiter's moon Io, which was subsequently verified by Voyager. This vulcanism is driven by tidal interaction with the planet and other satellites, a process that calculations and Voyager observations suggest may also be causing geologic activity in the form of water vulcanism on Jupiter's icy moon Europa and Saturn's icy moon Enceladus. Work has also been done on Jupiter's two largest icy moons, Ganymede and Callisto, including study of photometric properties from Voyager images, geologic mapping, quantitative study of surface topography, and theoretical modeling of geological processes and thermal evolution. Along with study of Enceladus, work in the Saturn system has concentrated on photometric studies of the enigmatic moon Iapetus, which is black on one hemisphere and white on the other. A theory has been developed to explain this, based on ultraviolet photochemistry of methane ice, which may help to understand the dark moons and rings of Uranus that will be viewed by Voyager in 1986.

(S. Squyres and R. Reynolds, Ext. 5491/5532)

## Planetary Ring Studies

Planetary rings are under study by scientists and NRC associates in the NASA Ames Space Science Division, along with university collaborators at Cornell, Berkeley, Santa Barbara, and Indiana. Ongoing analysis of the Voyager images of Saturn's rings has led to discoveries of spiral waves of two different types. The waves are similar in their physics to those thought to cause the structure of spiral galaxies, but are more tightly wrapped (like a watch spring) and are "forced" by strong resonances with Saturn's main satellites. Both horizontal (density) waves and vertical (corrugation) waves have been discovered. We have recently shown that these wave interactions may explain the mysterious internal heating of Saturn's moon Enceladus. Also, strong evidence has been obtained for the existence of moonlets embedded in a previously unexplored gap in the A ring. Sophisticated image-processing

facilities are being used to further analyze the Voyager images of Saturn's and Jupiter's rings. Theoretical work is focusing on the physics of gravitational and collisional effects in particle disks, including the behavior of resonances, linear and nonlinear wave damping, and the effects of a particle size distribution on the viscosity of the disk. The viscosity is crucial to understanding both the "thousand ringlet" structure in the B ring, which may be due to a viscous instability process, and the evolution of the disk as a whole. Many of the processes that occur today in Saturn's rings were probably of significance in the evolution of planets from the protoplanetary nebula, and thus are important to NASA's goal of understanding the origin of the solar system.

(J. Cuzzi, Ext. 6343)

## Heliospheric Plasma Studies

The hot outer solar atmosphere, or corona, expands outward through interplanetary space as the solar wind. The solar wind pushes nearby interstellar gas away from the solar system, so that the Sun and planets reside in a cavity, the heliosphere, that is shielded from interstellar gas and galactic cosmic rays. The plasma analyzer aboard Pioneer 10 is now sampling the solar wind in the outer heliosphere. Pioneer 10 has passed beyond all the known planets; still the heliosphere persists, with no indication of termination in the interstellar gas. Shocks from solar flares are still detected at the distance of Pioneer 10.

A similar instrument aboard the Pioneer Venus Orbiter continues to monitor the interaction of the solar wind with Venus. This interaction is thought to be similar in many respects to the interaction between the solar wind and comets. The solar wind is deflected by the planets' ionosphere, and sweeps back into a long, structured tail. Ionized atmospheric material found sunward of the ionosphere indicates a very rarified neutral atmosphere of atomic oxygen that extends far above the ionosphere. These atoms are ionized by sunlight or solar wind particles, and swept back through the tail of the planet and lost to space.

(A. Barnes, Ext. 5506)

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## Planetary Detection Studies

Most astronomers believe it likely that many stars have planetary systems like our solar system. But it is a difficult observational problem to detect such objects, and there is currently no evidence for the existence of any planets outside the solar system.

Researchers in the Space Science Division at NASA Ames are developing two new observational techniques for detecting planets around other stars. One is a method that combines the ancient concept of a transit telescope with modern high-speed electronics and light detectors. The star images are moved past an array of detectors that can time the passages of the images to a high precision, resulting in very accurate measurements of the star positions. This may enable the tiny "wobble" in the star's motion caused by a planet to be detected.

The other technique is to attempt to observe the quite small and transitory blocking of the star's light when a planet moves directly between the Earth and the star. The magnitude of the effect produced by the planet is much larger than in other proposed planetary detection schemes. However, only rarely and briefly will the planet and the star be lined up well enough for the starlight to be blocked. This means that a large number of stars must be monitored for long periods of time.

(J. Scargle and W. Borucki, Ext. 6330/6492)

## Numerical Experiments on the Dynamical Evolution of Galaxies

Environmental effects on galaxies in clusters of galaxies have been investigated using a three-dimensional, large N-body code on the large-scale computers at NASA Ames Research Center. The numerical experiments indicate that influences from a cluster environment appreciably change the internal dynamics of individual galaxies in the cluster. These experiments indicate that the observable rotation is reduced so that, initially, rapidly rotating galaxies are slowed to rotational velocities compatible with observations of elliptical galaxies. Experiments also show that galaxies moving through a cluster of galaxies suffer sig-

nificant frictional effects. This dynamical function is a result of the interaction of the galaxy with stars in the intracluster medium. Significant structural changes can occur over the lifetime of a galaxy.

Collisions and merging of disk galaxies embedded in halos have been investigated using the same experimental method. The interpenetrating collisions lead to a violent disruption of the disk galaxies. A variety of responses has been found for the disks ranging from stretched out, nearly linear forms to rapidly propagating ring-like patterns. The galaxy collisions studied are highly inelastic and lead to eventual merging into one galaxy. The final galaxy in these cases is a prolate, bar-like galaxy looking much like an elliptical galaxy. There is observational evidence that this may be the mechanism responsible for the formation of giant ellipticals in clusters. The important conclusion to be drawn from these experiments is that galaxies in a cluster respond to, and are affected by, their surroundings in significant, observable ways.

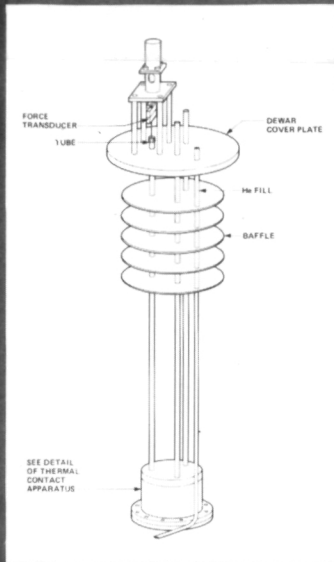
(B. Smith, Ext. 5515)

## Thermal Conductance of Pressed Contacts at Liquid Helium Temperatures

The optimum design of cryogenic instruments requires accurate thermal models. This is especially important for instruments where performance is sensitive to temperature. Infrared instruments such as the Shuttle Infrared Telescope Facility (SIRTF) and the Large Deployable Reflector (LDR) fall into this category. Present models are limited by a lack of knowledge of the low-temperature thermal conductance of the bolted joints that are typically used in the instrument to system interface. Previous studies of pressed contacts have been limited in scope, but have shown that the thermal conductance does not obey the Wiedemann-Franz law (which states that the ratio of thermal to electrical conductivities is proportional to the temperature).

An apparatus has been fabricated to measure the thermal conductance of pressed contacts at temperatures from 1.6 to 4.2 K under applied forces up to 670 N. The apparatus is immersed in a dewar filled with liquid helium. To obtain data

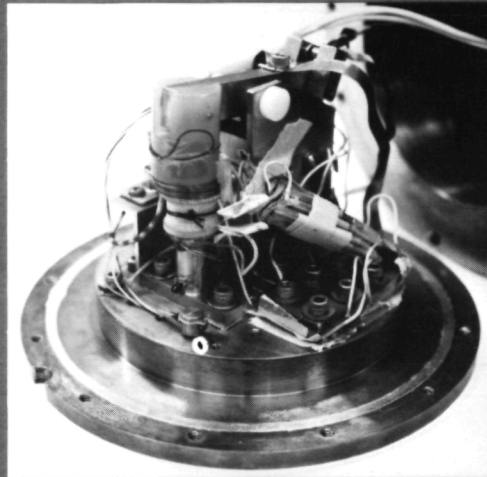
## THERMAL CONDUCTANCE OF PRESSED CONTACTS



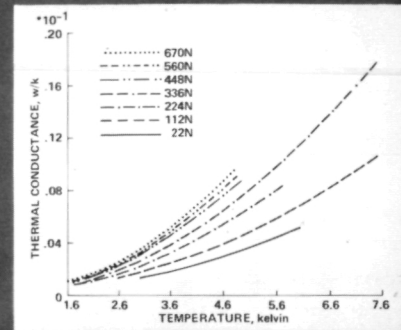
APPARATUS

### TESTING

1.6 → 6.0K  
0 → 670N  
STAINLESS STEEL  
BRASS  
ALUMINUM  
COPPER



PHOTOGRAPH OF COLD PLATE



DATA FOR COPPER SAMPLE

NASA

OAST  
Sponsored  
Technology

### *Thermal conductance measurement apparatus*

below 4.2 K, the temperature of the liquid helium bath is reduced by pumping on the bath. A pressure controller limits evacuation to achieve the desired liquid helium temperature.

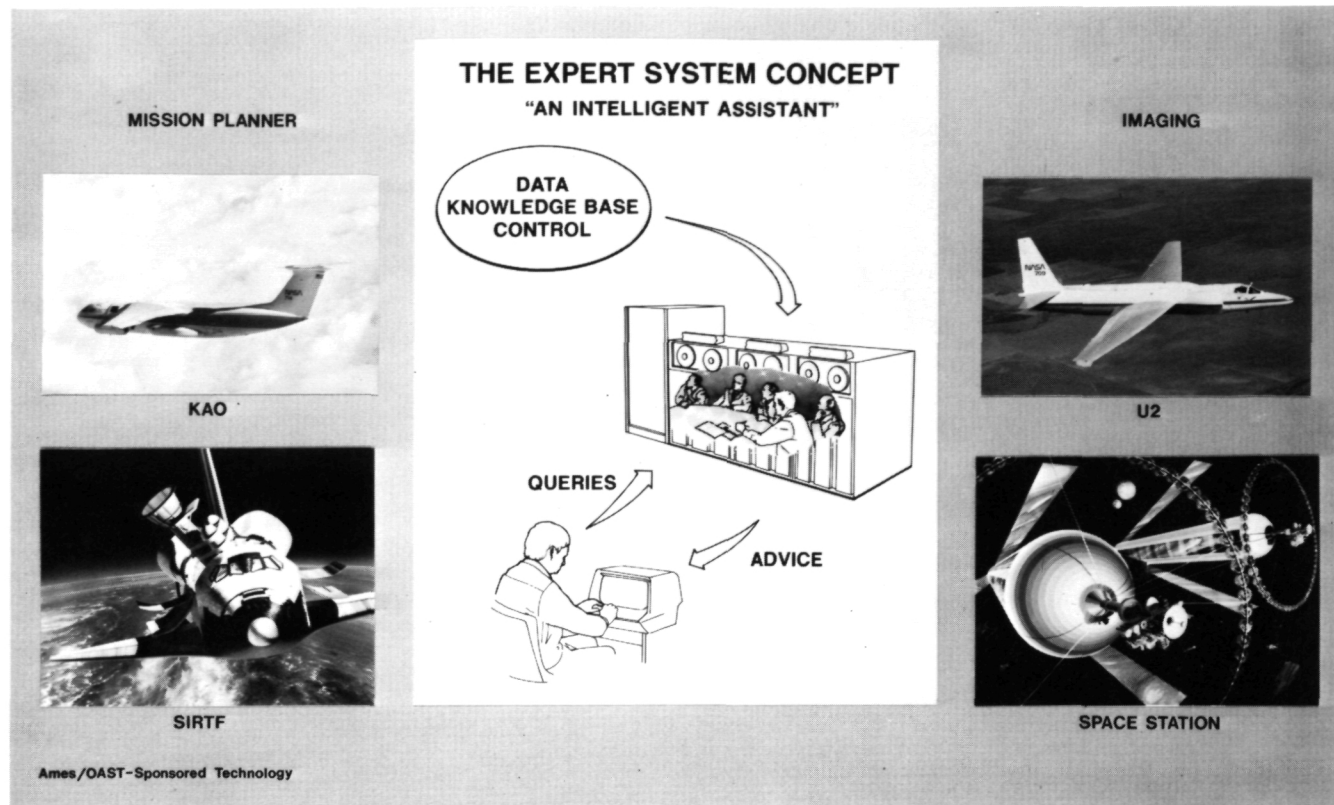
The actual pressed contact sample pairs have been fabricated from stainless steel, aluminum, oxygen-free high-conductivity copper, and brass. Five pairs of each material were prepared to evaluate the effect of different surface finishes on thermal conductance. Surface finishes of 0.1, 0.2, 0.4, 0.8, and 1.6  $\mu\text{m}$  were selected. The measurements of each sample pair were 10.2-mm diam and 10.2-mm length for the lower sample with 12.7-mm diam and 8.89-mm length for the upper sample. The larger diameter of the upper sample was chosen to assure that slight lateral movement would not prevent complete surface contact with the lower sample. Calibrated germanium resistance thermometers were installed in the upper

and lower samples. A heater consisting of manganin wire wound on an aluminum form was placed above the upper sample. Testing is performed from 1.6 to 4.2 K over the range of 0 to 670 N applied forces.

(L. Salerno, Ext. 6526)

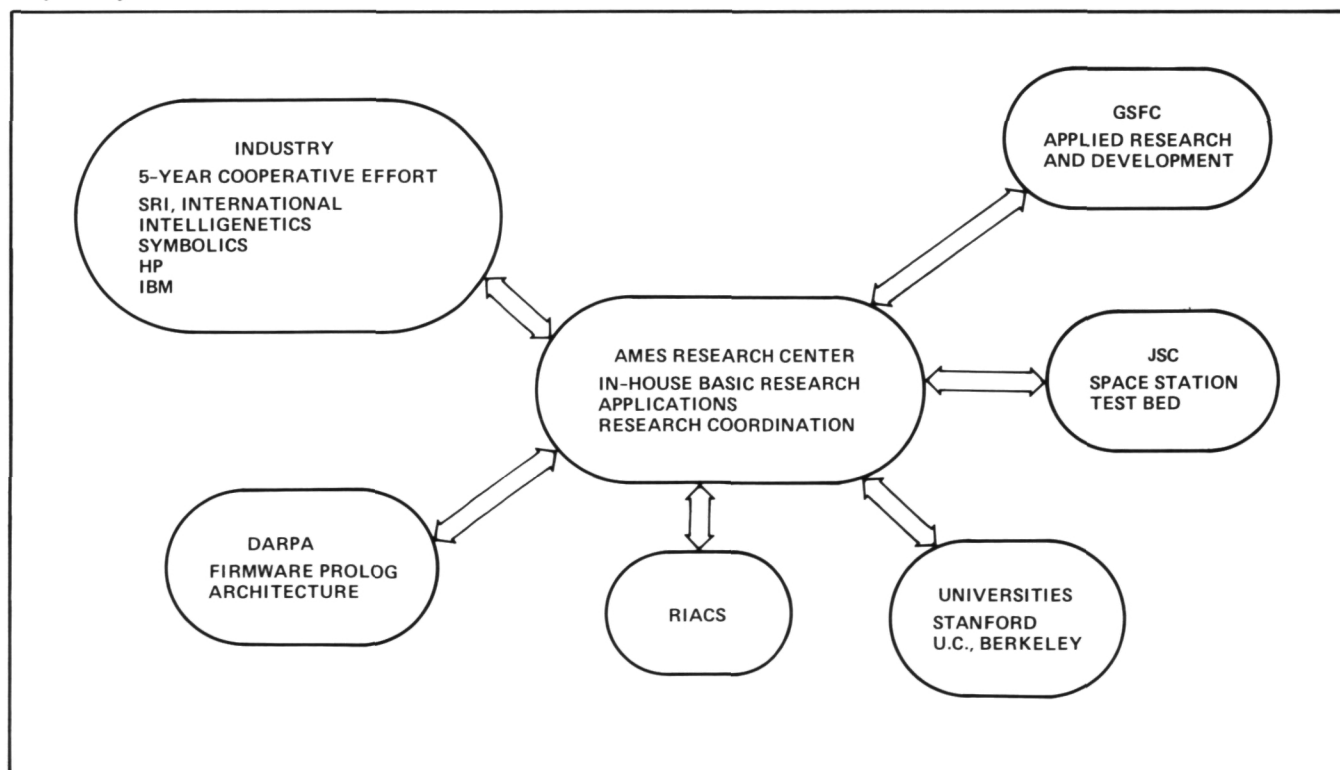
## Knowledge-Based Expert Systems

Basic research in the technologies required for a spaceborne image-based expert system has been initiated. Research is proceeding in four separate categories: spaceborne symbolic architectures including five eventual prototype very large-scale



*Expert systems application for astronomy and imaging*

*Expert systems research: Interfaces*



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integration (VSLI) chip sets; symbolic languages and natural language interfaces; image processing compatible with the symbolic architecture; and knowledge-representation software tools for user development of expert systems.

Currently 60% of the overall effort is with industry and universities and 40% is in-house. All external efforts are 5-yr cooperative efforts which are intended to complement and enhance the core effort being established at Ames, including technical interchange of personnel for "job enrichment." More of the overall effort will be shifted to Ames as the in-house core team acquires in-depth expertise and experience in expert systems. Cooperative agreements currently exist with industry (SRI International, IntelliGenetics, and Symbolics), universities (Stanford and U.C. Berkeley), DARPA, and other NASA Centers (GSFC and JSC). A research support agreement has also been negotiated with the Research Institute for Advanced Computer Science (RIACS) for on-site personnel support.

Two in-house applications of expert systems are currently under way. The first is a mission planner for infrared astronomy missions. The feasibility demonstration, scheduled for completion in Nov. 1984, is being implemented for the NASA Ames Kuiper Airborne Observatory, a national facility for infrared astronomy missions. This system will serve as the prototype for the Shuttle Infrared Telescope Facility (SIRTF), a late 1980s mission. The second application involves the identification and classification of aerosol particles related to the acidic rain condition. The data, gathered on the Ames U-2 aircraft, will be automatically identified, classified, and sorted by the expert system, tentatively scheduled for completion in Aug. 1984. This expert system will serve as the baseline for a potential space station Earth resources expert system experiment. Early feasibility demonstrations such as those described above will be accomplished at

regular intervals to ensure that the basic research objectives are well-focused and feasible for transfer to project applications.

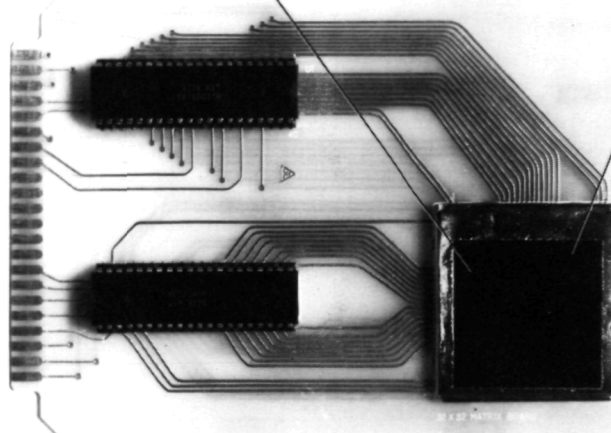
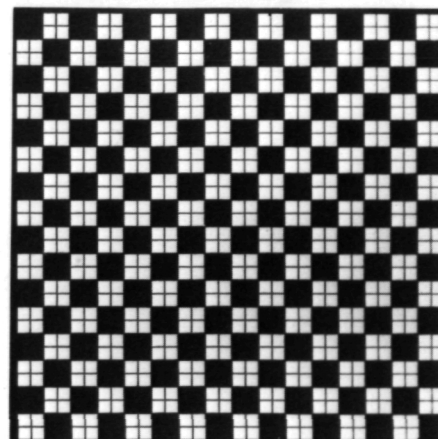
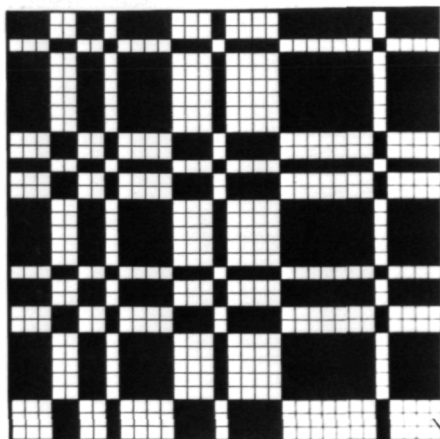
(H. Lum, Ext. 6544)

## **Liquid Crystal Programmable Mask for Optical Information Processing**

Programmable masks are the working devices essential for the practical realization of a functional optical computer. Because light from multiple sources can flow through each element of the mask, the mask is capable of parallel processing on a massive scale. Element masks ( $1000 \times 1000$ ) are within the reach of current technology. To evaluate the usefulness of liquid crystal arrays to programmable mask technology, we have constructed a  $32 \times 32$  liquid crystal array mask. The capability of the mask to be programmed with regular and irregular patterns is illustrated in the array mounted on a printed circuit board with its drive electronics. Sample patterns photographed from the array are also displayed.

The first working demonstration will be to use the mask for Hadamard image encoding. This demonstration is well suited for evaluating the limiting factors of the mask such as "on-off" contrast and speed. Hadamard transform image encoding is particularly useful at near-infrared wavelengths where background noise-limited performance is unobtainable, and the Fellgett multiplex advantage can be realized.

(J. Goebel, Ext. 6525)



NASA  
Ames Research Center

OAST  
Sponsored Research

*Liquid crystal programmable mask for optical information processing*

## Future Data Systems Concepts (Network Simulation and Analysis)

The emphasis during this first year has been on establishing simulation requirements for an advanced spaceborne data network applicable to the Space Station, and on finding a simulation language most suitable for network simulation on a general-purpose computer. Accomplishments to date include:

1. Establishment of an intercenter working group for data networks to coordinate development and research activities and to review and direct the network simulation capability.
2. Production of a draft functional specification describing the data network simulation capabilities which is being reviewed by the intercenter working group.

3. A literature search of reports on data network modeling.

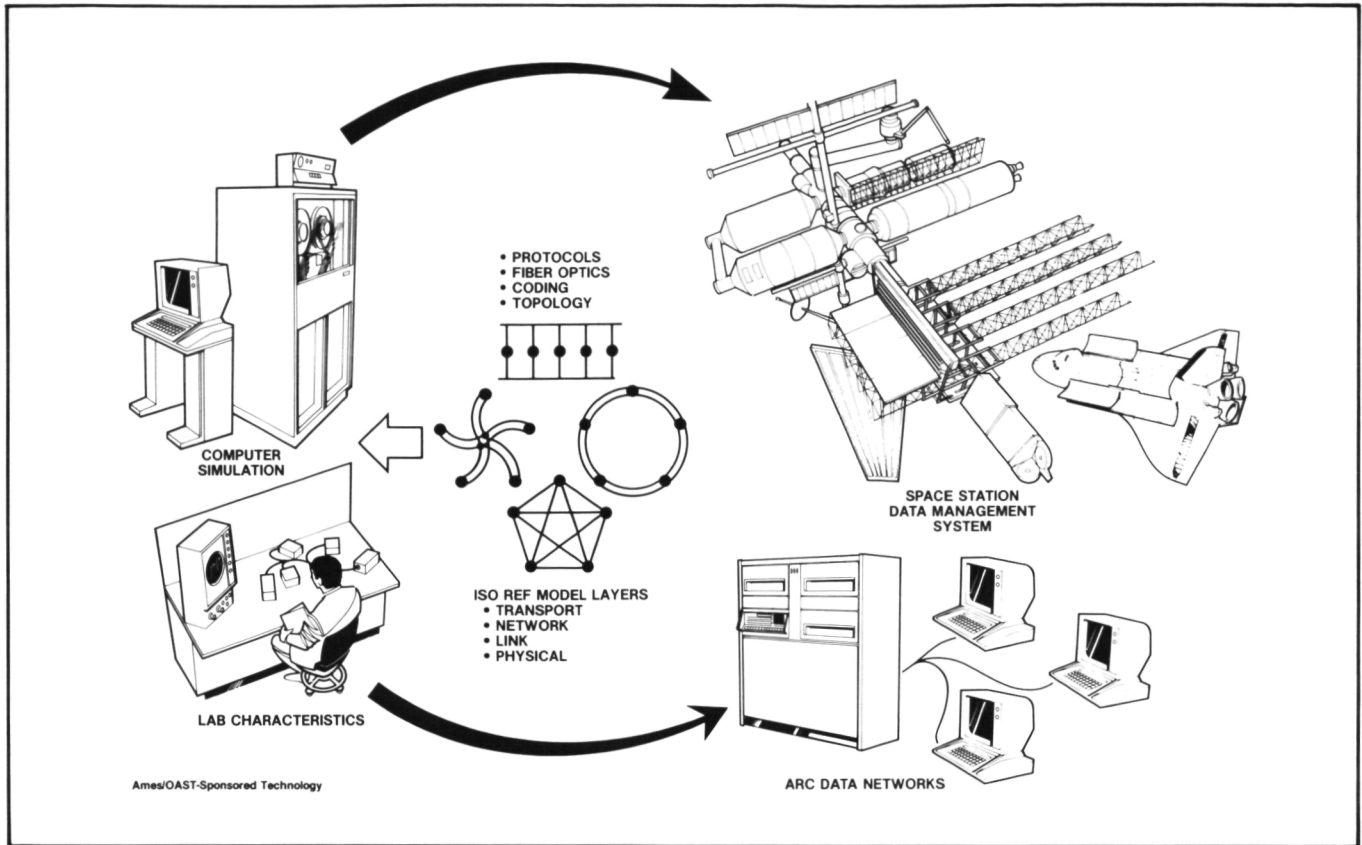
4. Tentative selection of a computer language, "Distributed System Simulator," based on the Extendable Computer System Simulator II (ECSSII) and Simscript II.5 languages which allows high-level constructs via control of library models and detailed programs to model new specific features or architectural differences.

5. Production of a prototype channel model which simulates a Carrier Sense Multiple Access-Collision Avoidance (CSMA-CA) protocol and a data load model, with draft documentation describing its use and functions.

6. Establishment of two target strawman network topologies and protocol to model, each based on the use of fiber optic cable.

A secondary effort is being made in the analytical development of network concepts:

1. The analysis of an efficient protocol which utilizes fiber optic characteristics is being started



*Future data systems concepts, network simulation and analysis*

under a grant to Stanford University.

2. The study of coding concepts for data networks is being conducted under a grant to the University of Santa Clara, which has resulted in several reports and conference papers on the performance of an alternate-channel access protocol, code division multiple access (CDMA), and on new code generation and decoding techniques for implementing it.

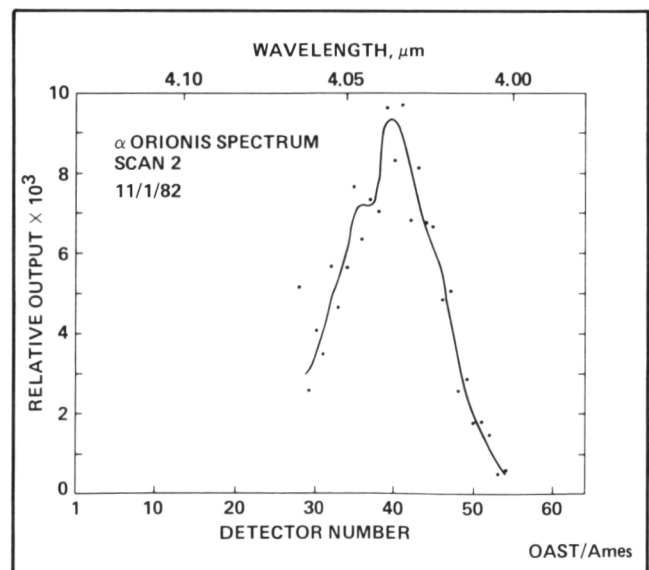
3. A survey report and tutorial has been written on high-rate error-correcting codes applicable to data networks.

(T. Grant, Ext. 6526)

## Astronomical Demonstration of $2 \times 64$ Silicon:Bismuth (Si:Bi) Infrared Arrays

For the first time, an integrated detector array was successfully used in an astronomical spectrometer. The charge-injection device (CID)

array, developed for NASA Ames by Aerojet ElectroSystems Company under OAST sponsorship, includes 128, 0.18-mm square detectors. It provides useful spectral coverage between about 4 and 18  $\mu\text{m}$ . Extensive laboratory testing at



*2 X 64 Si:Bi CID demonstration at Lick Observatory*

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NASA Ames was conducted to select the best of the three delivered arrays and to characterize their performance under simulated observing conditions.

In two observing runs (Oct. 1982 and July 1983) at the U.C. Santa Cruz Lick Observatory, the array was proven to operate effectively in a modified cryogenic grating spectrometer on the 120-in. Shane telescope. The array system performed reliably, and an infrared signal was obtained on all sources observed. Excellent noise levels, below 200 rms electrons, were obtained on the telescope. The high-resolution coverage provided by the array in an observation of the star  $\alpha$  Ori is illustrated. Importantly, the array showed the ability to do photometric observations, since spectra from sources of different temperatures could be ratioed to yield the proper spectrally weighted results. Also, the weak 3.9- $\mu$ m carbon sulphide absorption band was detected in the star S Cep. These findings demonstrate the potential for space application of this technology.

(C. McCreight, Ext. 6549)

## **Net Flux Radiometer**

A Net Flux Radiometer has been designed, which, with the intention to study the absorption of solar radiation, has been flown successfully on several airborne missions.

The most recent flights on a WP-3D Orion aircraft, were out of Alaska, Greenland, and Norway, and were to study Arctic absorption of solar radiation. This version of the radiometer had four spectral channels. Three narrow-bandpass spectral channels were used to measure the radiative flux divergence and a wideband channel was employed to monitor water vapor.

The detectors were wingtip-mounted and rotated in flight to expose them to up- and down-welling fluxes. All data acquisition and control were done using microprocessors. The outputs from the wingtip sensors were amplified and fed to a control console in the cabin, allowing the experiment to be controlled in flight by the investigator. Radiation data, sensor position, navigation data, and time were recorded in flight and later transferred to magnetic disks.

(W. Gore, Ext. 6503)

## **Infrared Grating Spectrometer**

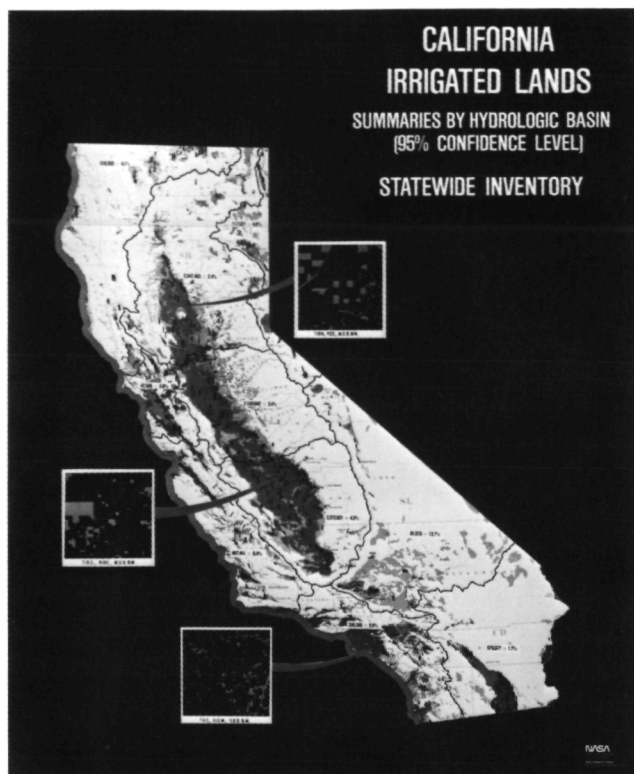
A data-acquisition system for a newly developed 40-detector Infrared Grating Spectrometer was flown successfully four times during 1983 on the NASA Ames Kuiper Airborne Observatory.

This Z80 microprocessor-based equipment is controlled by an Apple personal computer. The computer commands the data-acquisition system to control variable analog gain, selection for 64 channels, data system self test and diagnostics, strip chart channel selection, programmable chopper phase delay adjustment, analog-to-digital channel calibration, digital-to-analog channel selection and calibration, the total number of channels to sample, the total integration time, and start/stop scan commands. The data system integrates the detector samples and sends the results at the end of a scan to the Apple computer for further analysis. Real-time digital filtering using a weighted-average algorithm can be performed on up to four different preselected detector channels and displayed on a strip chart for in-flight evaluation of the data.

(R. Miranda, Ext. 6424)

## **High-Precision California Irrigated Lands Inventory Using Landsat Data**

A procedure to estimate irrigated land acreage using full-frame Landsat multitemporal imagery and a sample of ground data was demonstrated statewide in California through a cooperative project with the California Department of Water Resources (CDWR) and NASA Ames Research Center. With technical support from U.C. Berkeley and U.C. Santa Barbara, over 60 Landsat scenes of spring, summer, and fall dates over one growing season were fully enumerated for irrigated lands. In addition, over 1 million acres of ground data from areas statistically chosen within eight agricultural strata were acquired by CDWR. Landsat and ground measurements were linked, using regression estimators to compute estimates of irrigated acreage and associated precision errors. Statewide irrigated acreage results were 9.86 million acres with a relative standard error of  $\pm 1.7\%$  at the 99% confidence level.



This result was well within the goal of  $\pm 3\%$ . Acreage tabulations of the Landsat-based system varied from CDWR statewide projections by only 0.4%. Based on the success of the image-interpretation procedure for irrigated lands, a digital procedure was derived to emulate the manual process. A vegetation indicator, a ratio of Landsat multispectrum scanner (MSS) band 7 to MSS band 5, was used. This simple procedure proved very effective in separating irrigated from nonirrigated land in the arid environment of California and produced results on regional test areas that were comparable to the image-interpretation process. Techniques were also tested for the digital discrimination of crop types. Evaluation indicated that major crops (representing  $>10\%$  of the general agricultural region) can be separated with high accuracies. Lesser crops ( $<2\%$  of agricultural region) generally produced poor results. Using procedures derived from this first-time inventory of the entire state, the CDWR is currently monitoring irrigated lands within a number of selected hydrologic basins.

(D. Lumb, Ext. 5900)

## Airborne Astronomy

NASA's Kuiper Airborne Observatory (KAO), operated as a national facility for infrared astronomy, contains a 91.5-cm bent Cassegrainian telescope mounted open port in a C-141A airplane (NASA 714). The airborne astronomy project is managed by the Ames Medium Altitude Missions Branch and assisted by the Ames Flight Operations Division. Informatics General Corp. and Northrop Services, Inc. provide technical, engineering, and airborne data processing support, respectively.

In FY 1983, 72 flights providing 540 hr of flight time, were made for 24 investigator teams. Seventeen Principal Investigators came from U.S. universities, two from Australian universities, four from NASA Ames, and one from NASA Goddard.

The highlight of the year was a 6-wk expedition to Australia in May and June 1983; an earlier deployment to Australia had been made in 1977. The objective was to study infrared celestial objects in the far southern skies that are not observable from the northern hemisphere. Fifteen flights providing 105 hr, were flown for seven investigators out of the Richmond RAAF Base, near Sydney. In many of the deep southern objects, such as the Magellanic Clouds, proto-stars are at a different stage of evolution than those observable in the northern hemisphere. Many additional data were obtained from the southern sources to fill in theories on processes of star formation.

FY 1983 marked the tenth year of observation for the NASA C-141/KAO. Much progress has been made in the development of the observing instrumentation mounted on the KAO and in the collection of data throughout the infrared spectral region. Multichannel photometry and high-resolution spectroscopy are being conducted routinely out to  $500\ \mu\text{m}$ . In the submillimeter region, 0.5 to 1.0 mm, both optical and heterodyne (radio) techniques are being used. The physical and chemical conditions in star formation regions are being systematically defined. About 50 molecular, ionic, and atomic species have been identified; and their intensity and spatial distribution have been mapped in such regions as cold molecular clouds and hot shocked clouds.

(L. Haughney, Ext. 5339)

## Fine Guidance Sensor for the Shuttle Infrared Telescope Facility

A technology evaluation study has identified the model 53612 Charge Coupled Device (CCD), manufactured by the RCA Corporation as the leading candidate solid-state detector for use as the internal star tracker on the Shuttle Infrared Telescope Facility (SIRTF). The 53612 CCD is the successor to the 53601 CCD, and differs from the latter device by being thinned and backside-illuminated as well as by having an extra mask layer incorporated for antiblooming control and a reflecting layer for enhanced blue response.

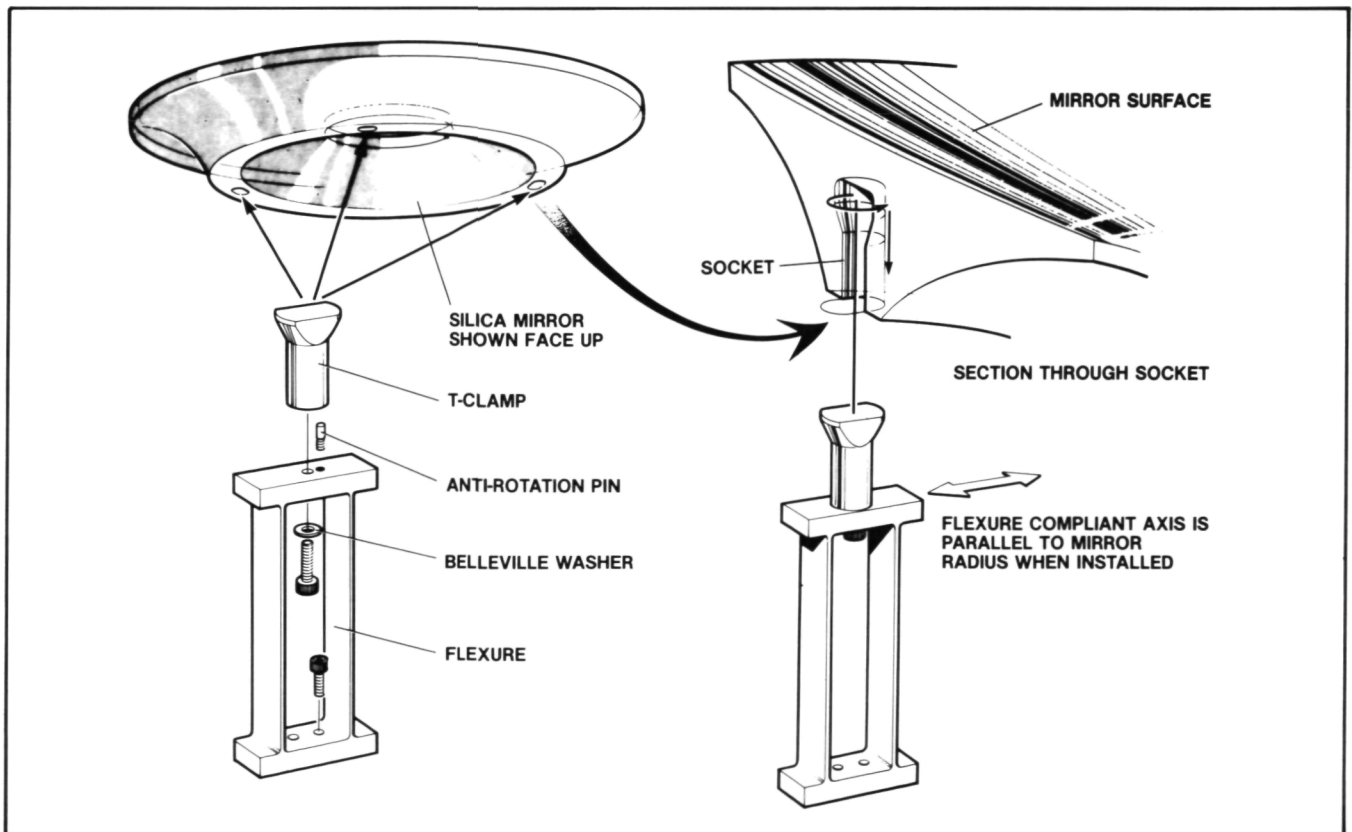
An early production version of this device was procured for testing in the SIRTF prototype Fine Guidance Sensor (FGS) brassboard. Initial evaluation under floodlit conditions indicated that minimum noise of approximately 300 electrons per pixel could be achieved by operating at  $-30^{\circ}\text{C}$ .

Following installation of the device in the 20-cm FGS prototype, a field test of sensitivity was performed at the Table Mountain Test Facility. The 53612 CCD demonstrated a gain in sensitivity of approximately one visual stellar magnitude for a given integration time compared with the 53601 CCD. Laboratory test and analysis is continuing to estimate possible further performance improvements.

(L. Lemke, Ext. 6531)

## Mounting of Cryogenically Cooled Silica Mirrors

The technology of mounting silica mirrors for cryogenically cooled infrared telescopes in space is under development at NASA Ames. Cryogenic cooling to near liquid helium temperature (less than 10 K) is required to reduce the thermal emission of the telescope to the extremely low levels where the great sensitivity of the detectors may be utilized.



*Mounting of cryogenically cooled silica mirrors*

Some glassy materials, such as high-purity fused silica and fused natural quartz, have excellent optical performance at cryogenic temperatures, but require new approaches in mounting because of the large differential thermal contraction that exists between the silicas and aluminum, a typical telescope structural material for space applications.

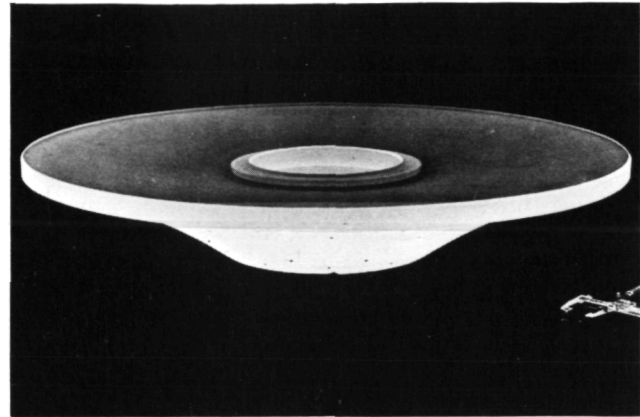
Under a grant to the Optical Sciences Center of the University of Arizona, a mirror mount has been developed which incorporates clamp and flexure assemblies. Three T-clamp and parallel spring guide flexure assemblies are attached to the back of the mirror,  $120^\circ$  apart. An assembly is attached by insertion of the T-clamp into a mirror socket via its elongated hole. After rotation of the T-clamp through  $90^\circ$  in the socket, the clamp is pulled down against a conical bearing surface machined into the socket. A bolt through the top of the flexure pulls the T-clamp down to clamp the mirror. The flexure is aligned with its compliant direction parallel to the mirror radius. This allows the structure to contract with acceptably small bending and shear loads transmitted to the mirror. An antirotation pin prevents the T-clamp from rotating after assembly.

(R. Melugin, Ext. 6530)

## Development of Silica Mirrors for Cryogenically Cooled Infrared Telescopes

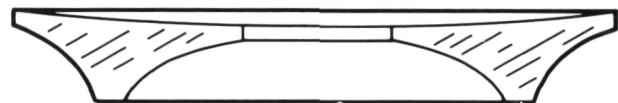
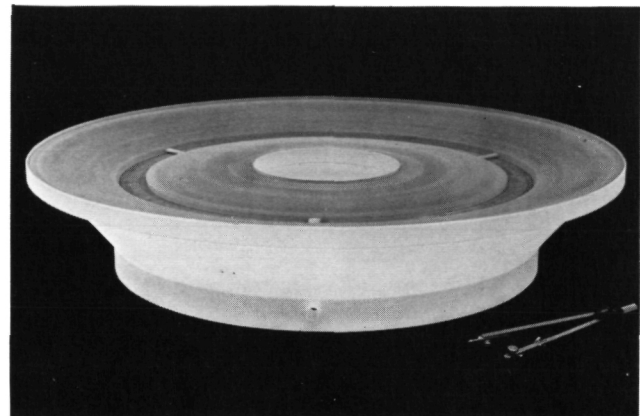
The development and evaluation of several types of silica mirrors at cryogenic temperatures is under way at NASA Ames. Two 50-cm diam lightweight mirrors have been fabricated by the University of Arizona, Optical Sciences Center. Using a unique, cryogenic test facility developed at Ames, the mirrors were tested at 10.5 K or less. Test results indicate that the image quality of cryogenically cooled, infrared telescopes with silica mirrors will be improved relative to metal mirrors without correction of the mirrors for distortion caused by the extreme temperature range experienced on cooldown.

A third mirror, developed by Itek Corporation and Heraeus-Amersil, has been tested under contract to Ames by Itek. This 65-cm-diam mirror



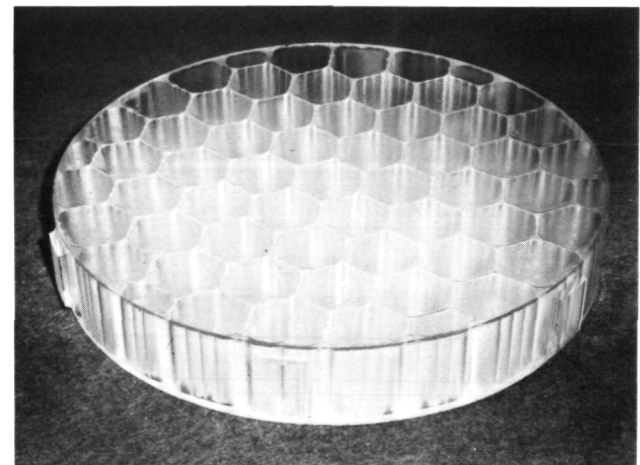
2.5 cm

SINGLE ARCH (T08, E)



DOUBLE ARCH (7940)

*University of Arizona silica mirrors*



*Itek/Heraeus mirror*

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is of ultra lightweight, sandwich construction and weighs 15.9 kg. Since test conditions for this mirror were not optimum, its performance is believed to be better than the data indicate. Further tests are warranted.

Tests have also been completed at Ames on an even lighter 50-cm-diam, frit-bonded, fused silica mirror developed by Kodak for the Department of Defense. This mirror, weighing only 4.3 kg, was tested at 9 K. Results will be available in late 1983.

Cryogenic tests of the double-arch mirror, with a specially developed mount, will be conducted in the last quarter of 1983. Tests of mirrors made of other materials such as machined beryllium and hot isostatic pressed (HIP) beryllium will be conducted in 1984.

(R. Melugin, Ext. 6530)

## Properties of Molecules and Atomic Clusters

The determination of the properties of molecules and atomic clusters from calculations continues to produce important results for predicting and understanding the properties of matter. Studies have been completed on atoms and diatomic molecules consisting of transition metals (Ni, Cu, Fe, Sc, and Cr) and gaseous species (H and O) which have led to a detailed understanding of metal-metal and metal-gas chemical bonding for simple systems. More approximate, but comprehensive, calculations have been completed for clusters of up to 49 atoms (e.g.,  $\text{Ni}_5$ ,  $\text{Ni}_5\text{O}$ ,  $\text{Ni}_{25}\text{O}_5$ ,  $\text{Fe}_n$ , and  $\text{Fe}_n\text{H}$  where  $n = 30, 36, 39$ , and  $48$ ). This information has been used to resolve misinterpretations on nickel-oxygen surface physics experiments and is leading to an understanding of one aspect of how hydrogen dissolved in ferrous materials drastically increases the metal's susceptibility to crack initiation and propagation.

Studies have also been undertaken to help understand the mechanism of polymeric material degradation in low Earth orbit which has been observed during Space Shuttle missions. Model studies of Kapton ( $[\text{C}_{22}\text{H}_{10}\text{O}_5\text{N}_2]_n$ ) photochemistry and oxidation have been completed. It appears that the initial chemical attack occurs with oxygen-atom insertion into the phenylenic

hydrogen bond. Using p-hydroxyaniline as a model, we have found this process to be energetically favorable. However, in the perfluorinated analog it is blocked, which leads to the conclusion that fluorinated polymers might be better candidates for space applications in low-altitude orbits.

(R. Jaffe, Ext. 6458)

## Atomistic Simulation of Materials

The process of crack propagation has been simulated in the computer employing a molecular dynamics technique based on the Nordsieck-Gear algorithm. The present software is able to handle systems containing up to 10,000 particles interacting via two-body potentials. Particles in the system have been treated discretely, and quantities such as energies and stress components are all recorded for many thousands of time steps for statistical averagings. To model the crack propagation process, a tensile load was imposed on a perfect two-dimensional triangular lattice (which is the basal plane of a hexagonal, close-pack crystal) containing a small surface crack. The system maintained its initial configuration (i.e., no crack propagation was detected) up to 3.5% elongation and exhibited elastic behavior. During this elongation procedure, the concentration profile of the stresses in the load direction displayed a progressively increasing "high stress region" at the crack tip, as predicted by continuum theories. At the 4% elongation the crack started to propagate with a rate close to the sound velocity. Further propagation of the crack was associated with the monotonic decrease in the averaged total stress of the system. This, in turn, affected the crack propagation velocity, which was found to be linearly related to the averaged total stress.

These findings are consistent with known experimental results and indicate that the present simulation method can be used to elucidate complicated mechanisms which are important in the fundamentals of material strength and failure. This work was conducted in collaboration with Dr. T. Halicioglu of Stanford University.

(D. Cooper, Ext. 6213)

## Design of Diagnostic Probes for Combustion

The results of calculations of spectroscopic properties of diatomic and triatomic molecules are being used to design new nonintrusive diagnostic probes for combustion applications. Theoretical studies are under way to devise methods of monitoring trace species concentrations and gas temperatures encountered during the burning of hydrocarbon fuels. These results are being provided to assist researchers working in experimental aircraft combustion programs at NASA Langley Research Center and NASA Lewis Research Center.

An optimized design is being developed for a probe which can be used to determine the hydroxyl concentration and temperature in scramjet engines by monitoring the OH ultra-violet absorption bands. Ames' detailed spectral model for this process is being used to implement the experiment at Langley by Dr. B. Northam.

Other calculations have been undertaken to simulate multiphoton processes such as Coherent Anti-Stokes Raman Scattering and two-photon absorption in  $H_2$ ,  $O_2$ , and  $NO$ . The results of these calculations have been used to provide accurate synthetic spectra, which take into account instrumental effects such as the Stark broadening and shifting of the spectroscopic lines caused by the use of powerful laser fields. This project is being carried out in collaboration with Dr. W. Huo of the University of Notre Dame.

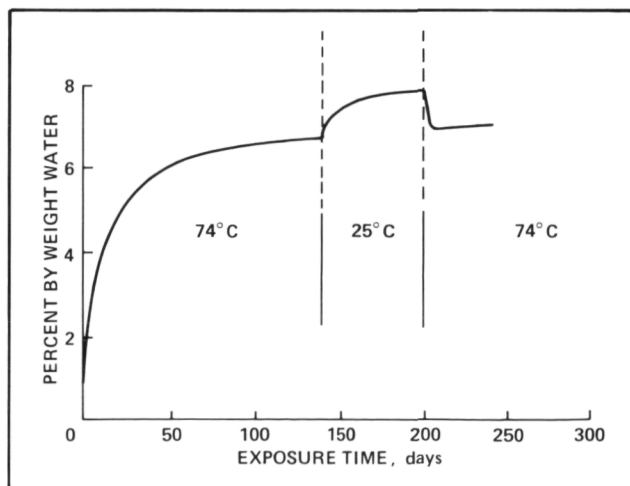
A spectroscopic process which can be used to measure  $C_2H$  concentrations is being developed in collaboration with University of California scientists, Drs. K. Wilson and E. Heller. For this study the infrared electronic and vibrational spectra of  $C_2H$  are being synthesized. The low-lying  $^2\Pi \leftarrow ^2\Sigma^+$  electronic transition is much stronger than the vibrational transitions and may be used to monitor  $C_2H$  concentration in hydrocarbon flames.  $C_2H$  is believed to be an important transient combustion intermediate and soot precursor, but has not been directly observed in combustion experiments.

(R. Jaffe, Ext. 6458)

## The Reverse Thermal Effect of Moisture Absorption in Epoxy and Epoxy-Matrix Composites

Thermal expansion and swelling of epoxy resins and epoxy-matrix composites have been studied in detail. It is found that the cured epoxy resin will swell by an amount less than the volume of water absorbed and that swelling efficiency varies with moisture content of the polymer. An epoxy resin near saturation at a higher temperature will increase moisture content when placed in water at a lower temperature, and, when returned to the higher temperature water, the moisture content will rapidly decrease. This finding is unique and has been termed the reverse thermal effect of moisture absorption in epoxies. A model has been developed to explain this phenomenon in terms of an inverse temperature dependence of free volume in the epoxy. This model has been successfully applied to better understand thermal-spike effects observed in graphite/epoxy laminates and promises to significantly improve our understanding of the structural behavior of glassy polymers, including the occurrences of various structural transitions with temperature.

(M. Adamson and H. Nelson, Ext. 5406/6137)



*The reverse thermal effect of moisture absorption in a typical epoxy resin exposed to moisture*

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